Jet Propulsion Laboratory
California Institute of Technology

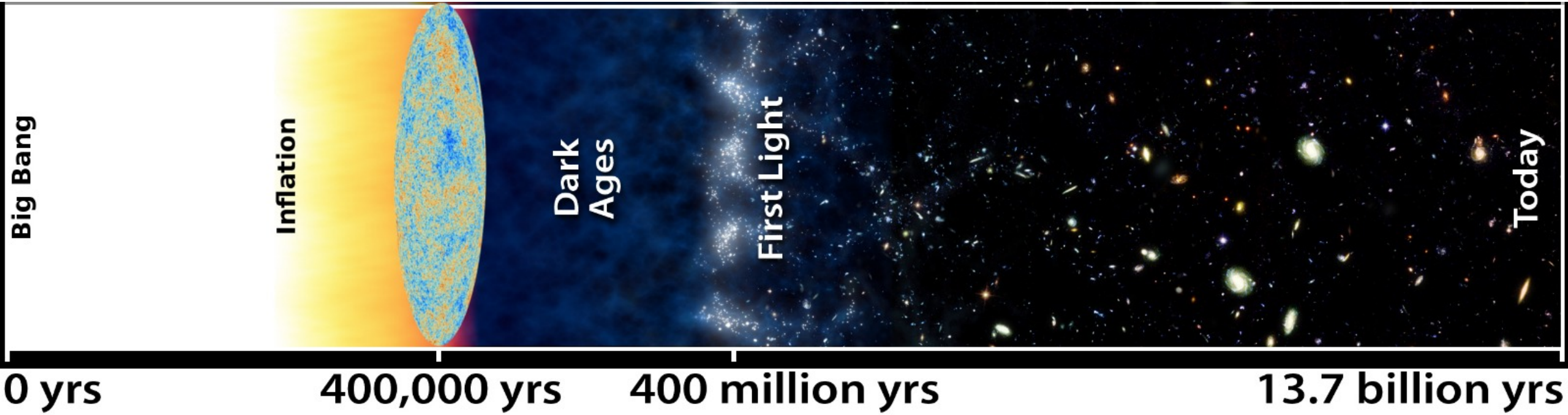
The accelerated universe through weak lensing

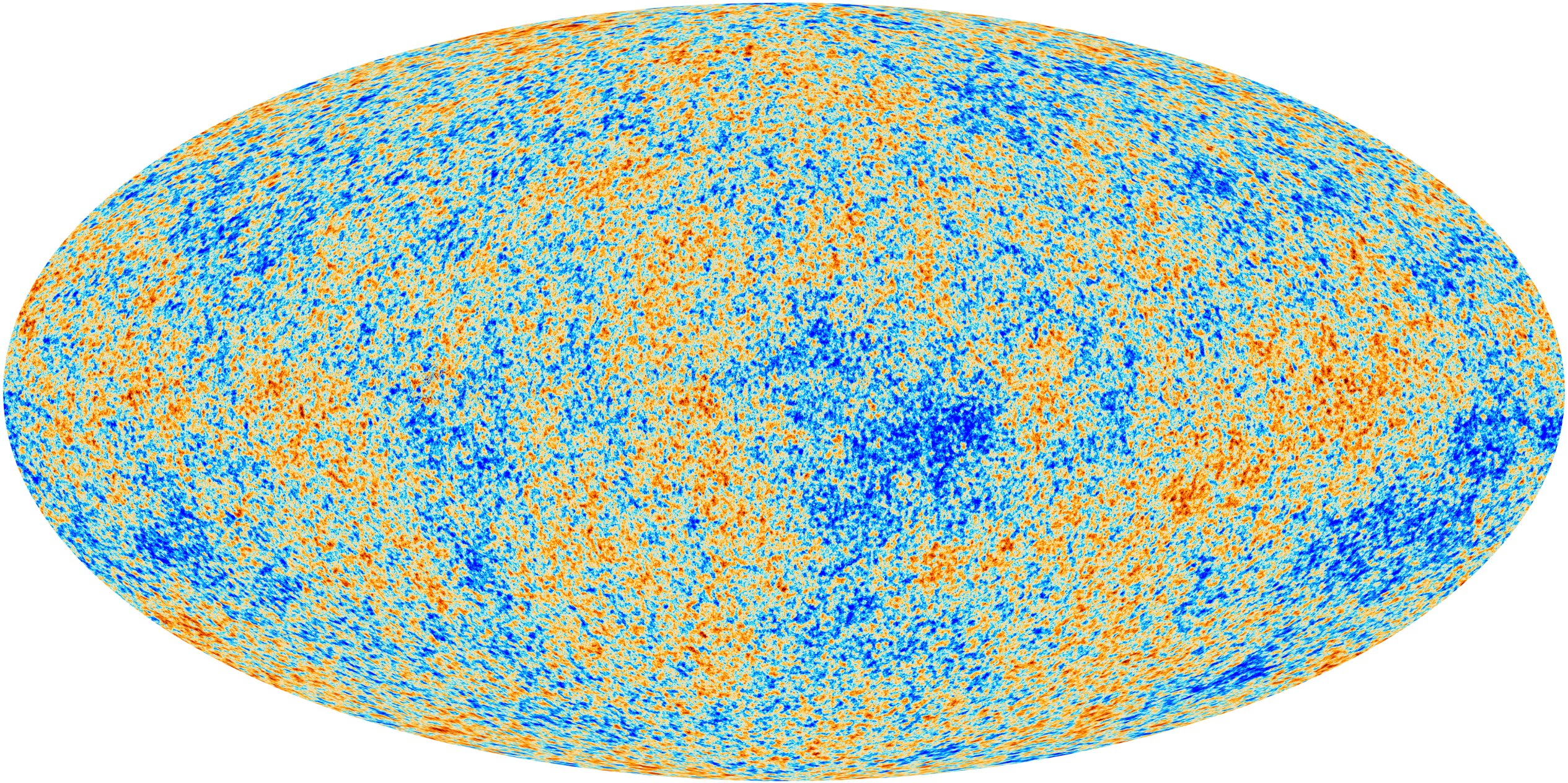
Agnès Ferté

Jet Propulsion Laboratory, California Institute of Technology

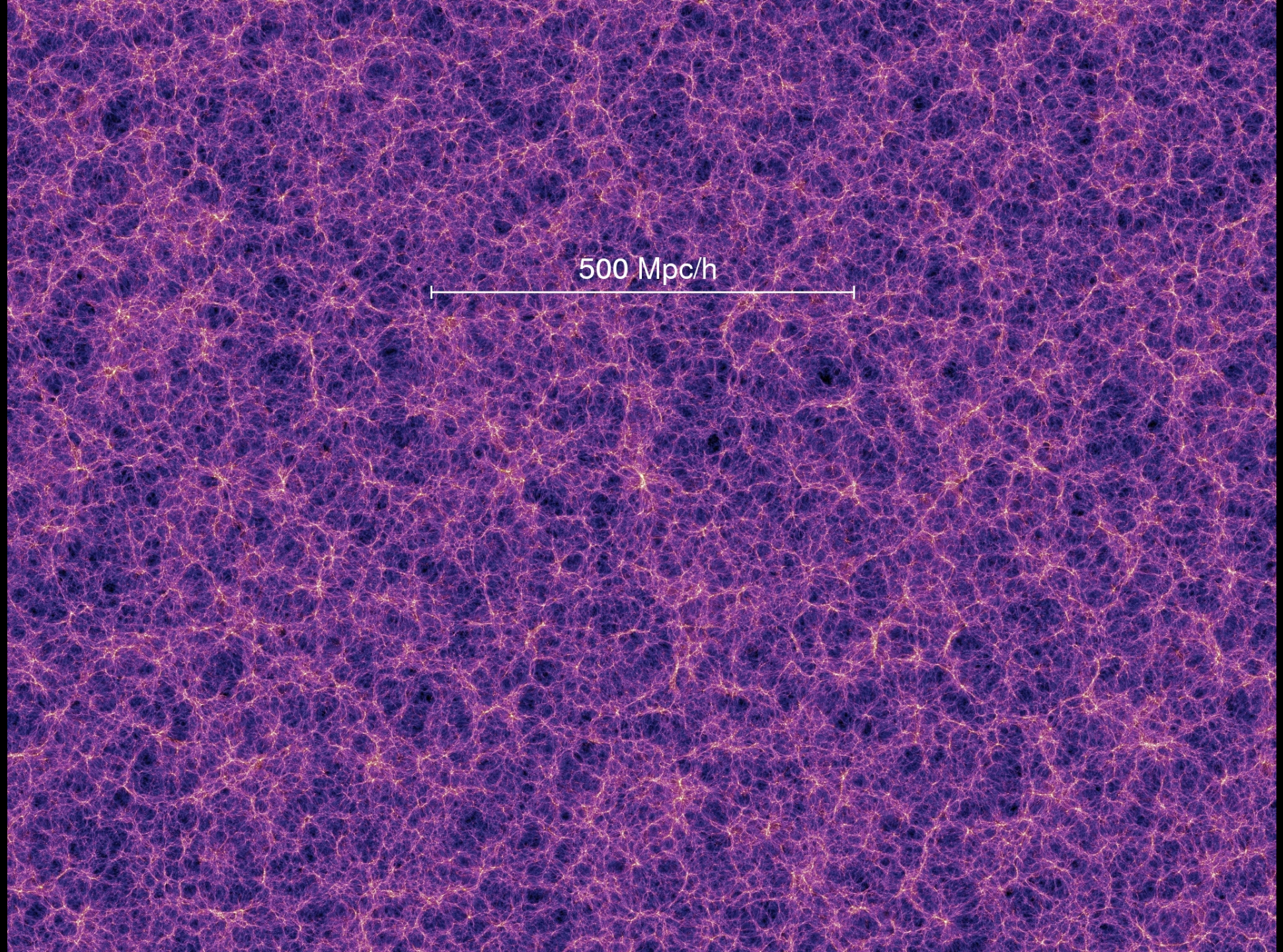
The standard model of cosmology: ΛCDM model

Credits: ESO



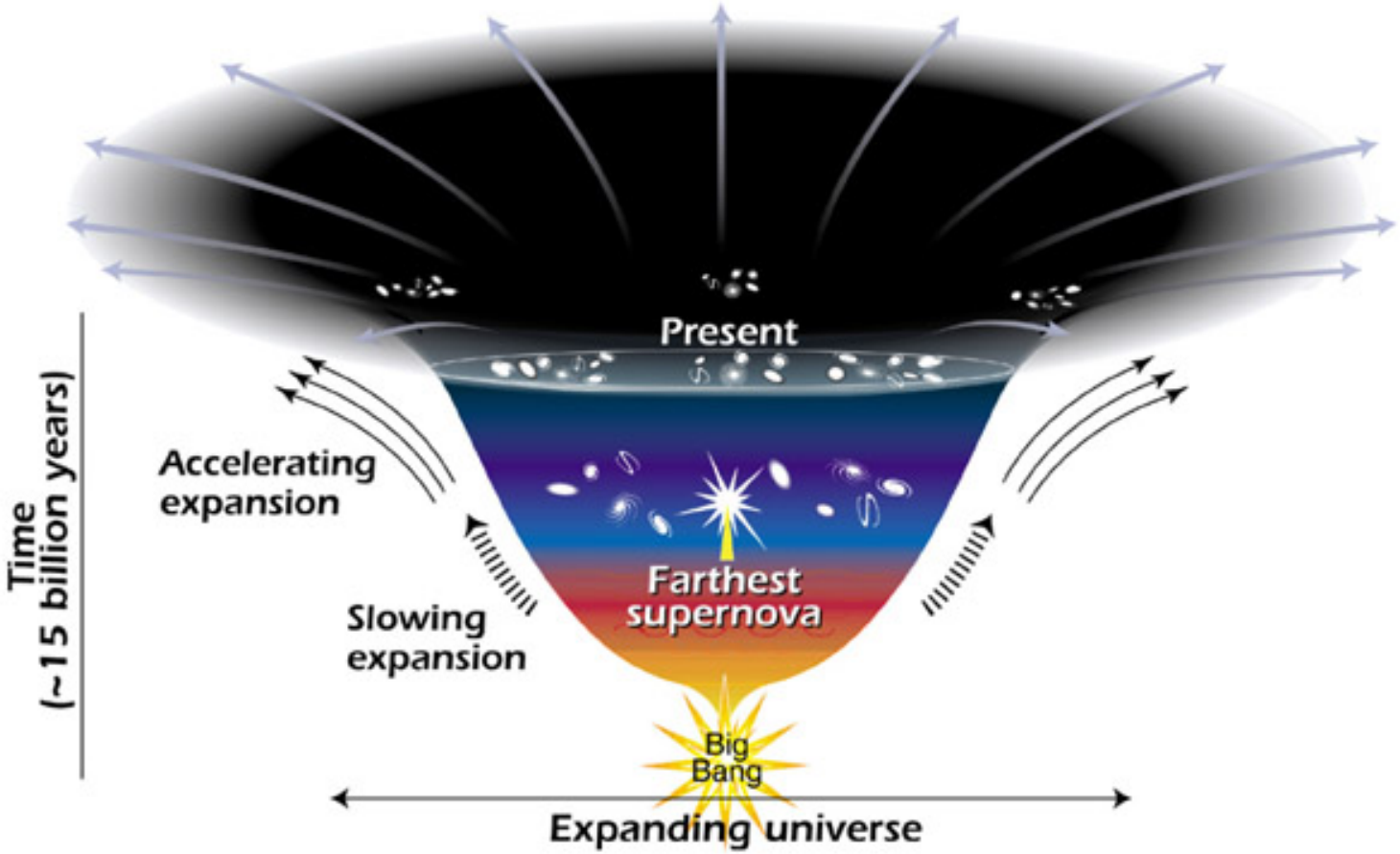


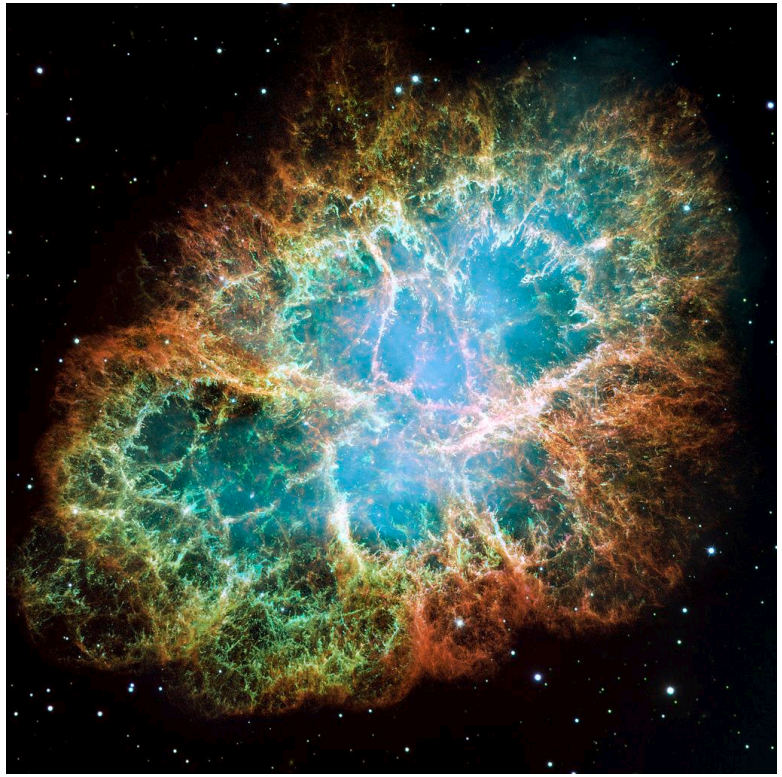
Planck Collaboration and ESA



By Millenium simulation Project

Cosmic acceleration





Explaining cosmic acceleration

$$G_{\mu\nu} = 8\pi T_{\mu\nu} - \Lambda g_{\mu\nu}$$

Dark Energy: fluid with equation of state w

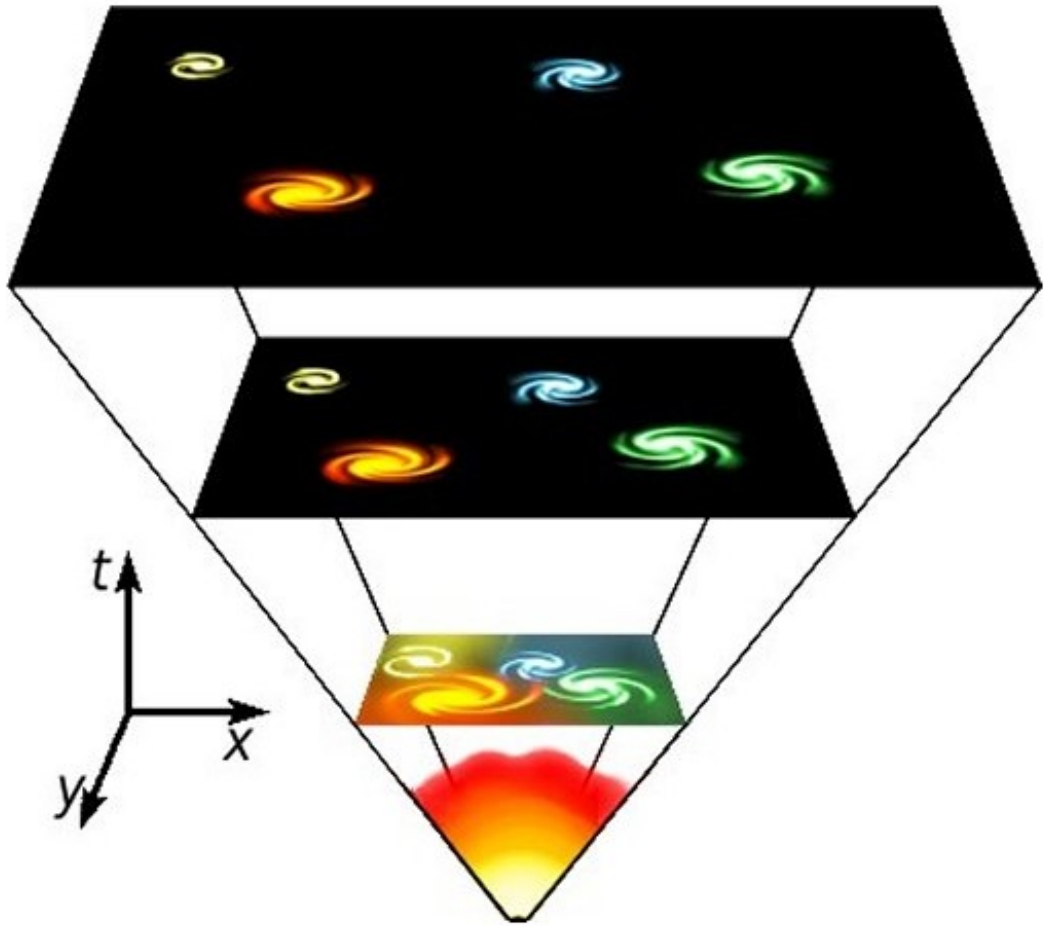
- w = -1 i.e. a cosmological constant Λ
- w is constant
- w depends on time: $w(a) = w_0 + (1-a)w_a$

Modified Gravity: modification to General Relativity

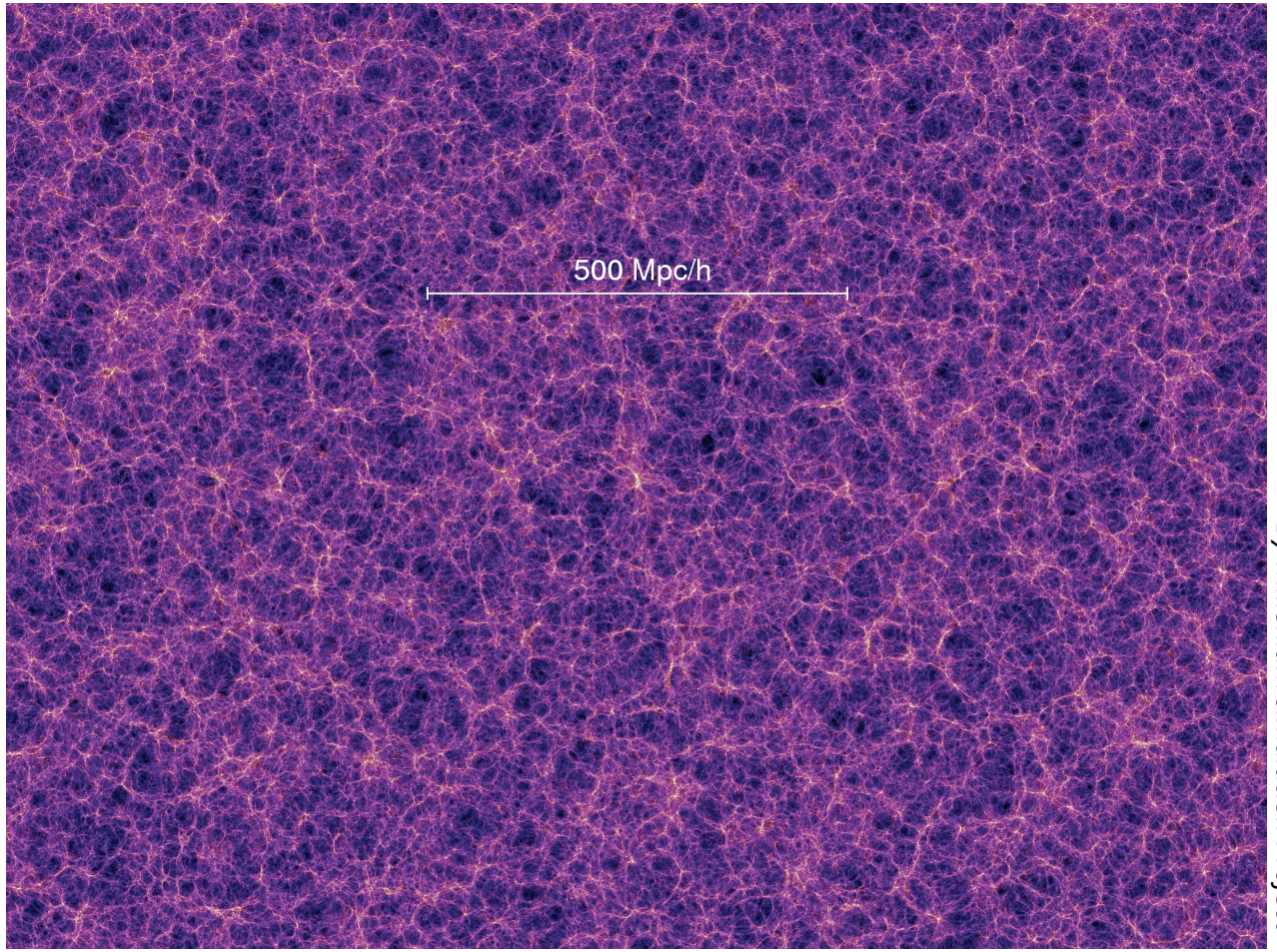
- Modify GR action
- Phenomenology of modified gravity: parametrize potentials probed by observations
- Effective Field Theory of dark energy

Probing cosmic acceleration

Evolution of the expansion



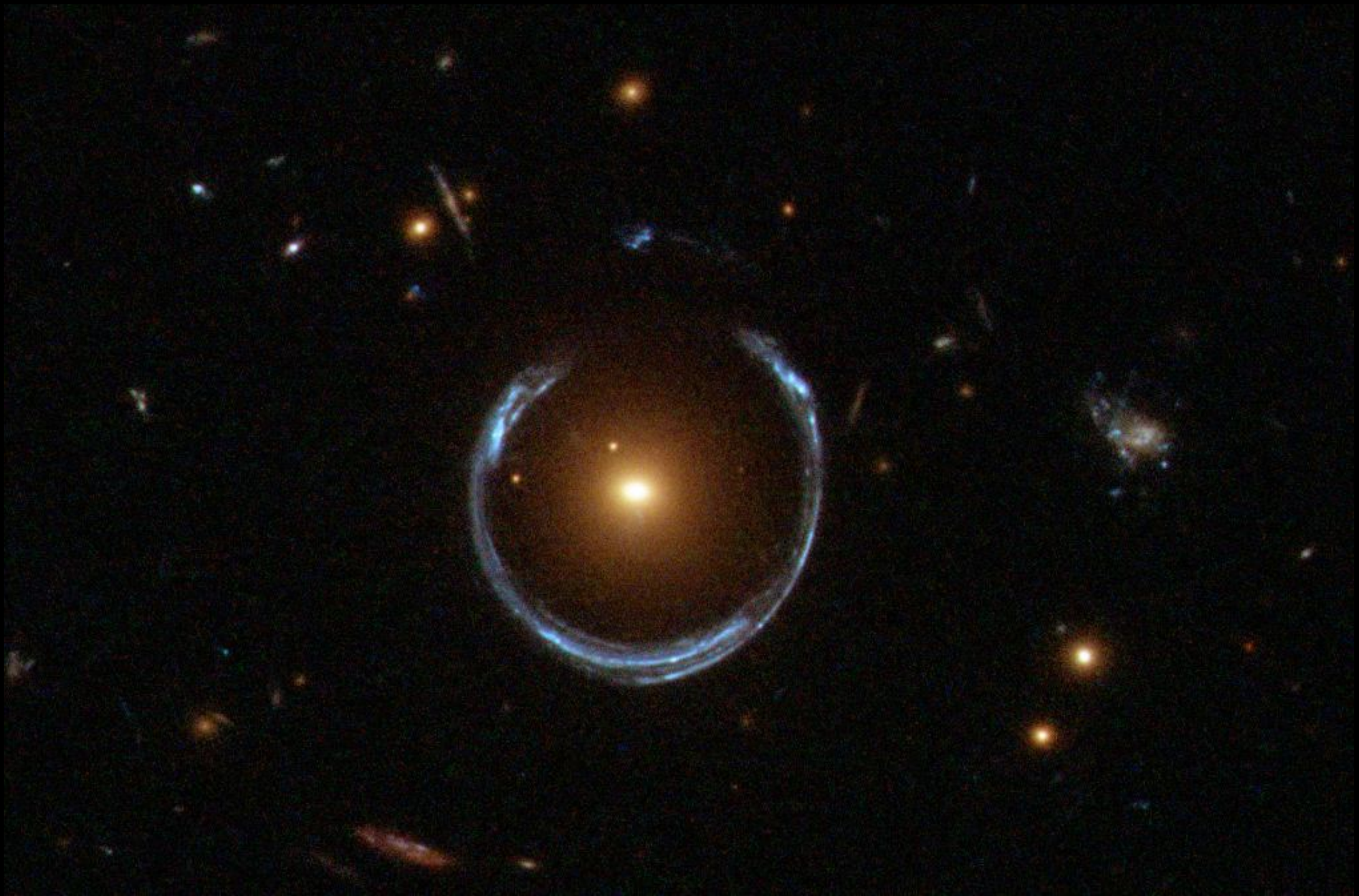
Growth of structure



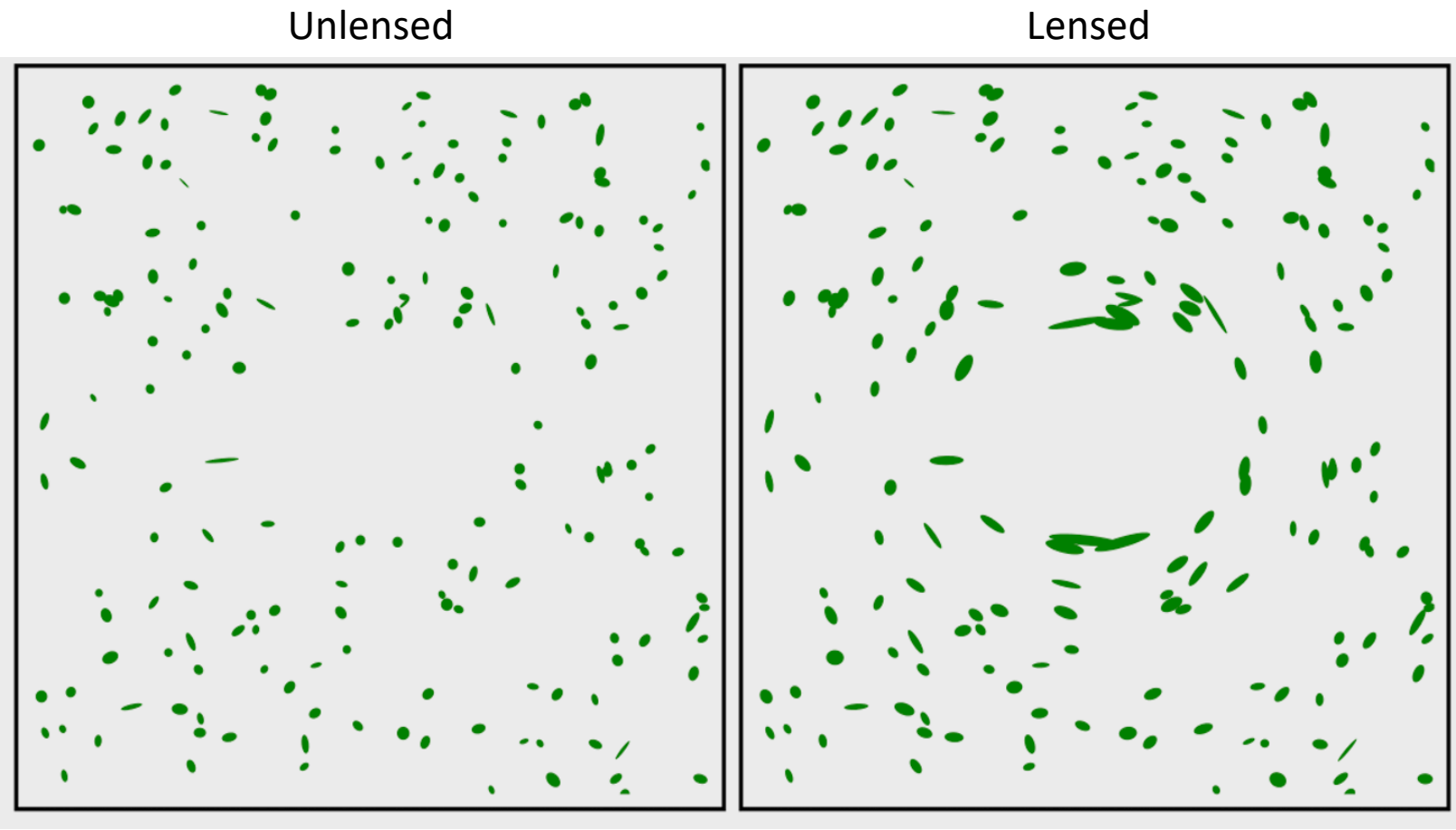
By Millenium simulation Project

Weak lensing to probe cosmic acceleration

From galaxy surveys to cosmology



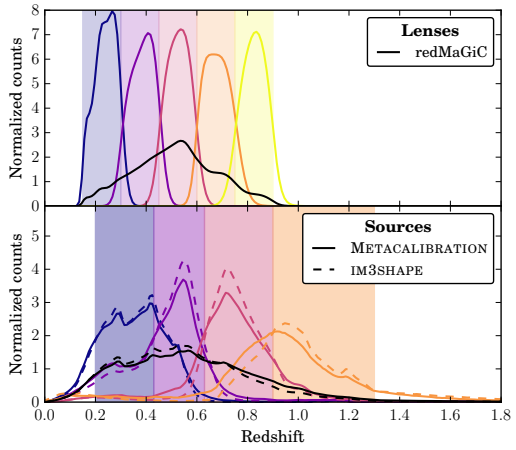
Weak gravitational lensing

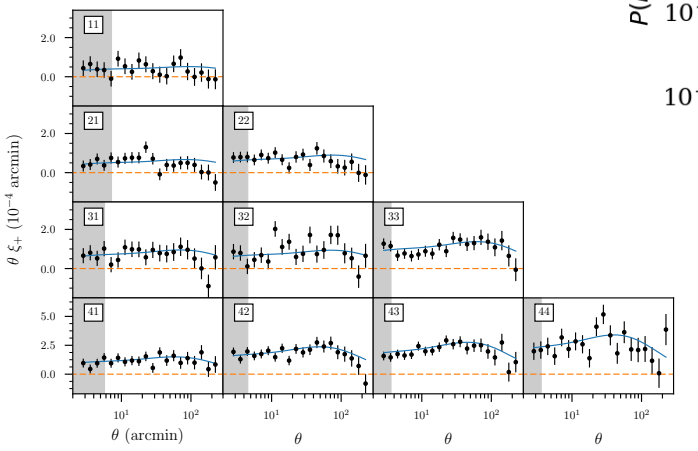


Deformation of images of galaxies by large-scale structures in the universe

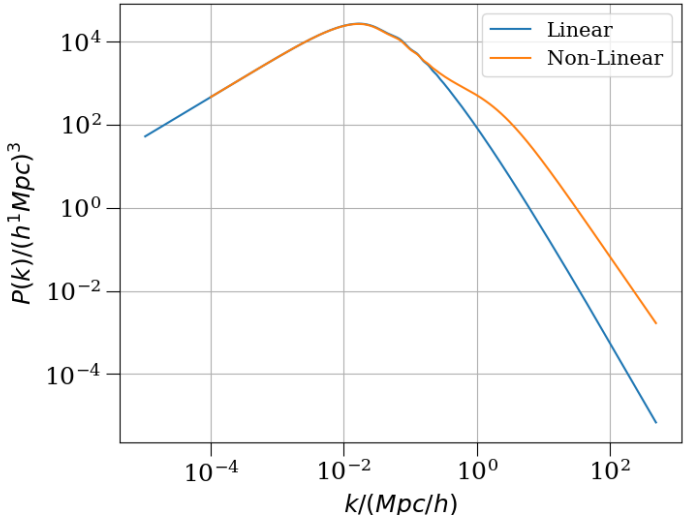
DATA

MEASUREMENTS

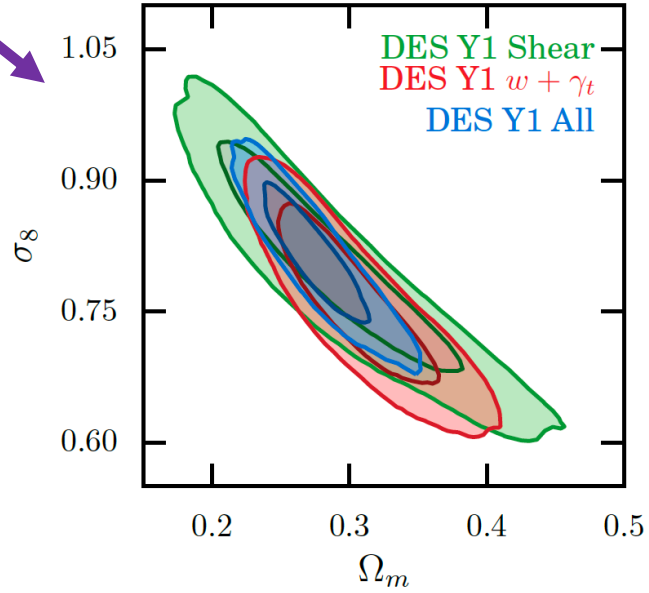




THEORY



COSMOLOGY



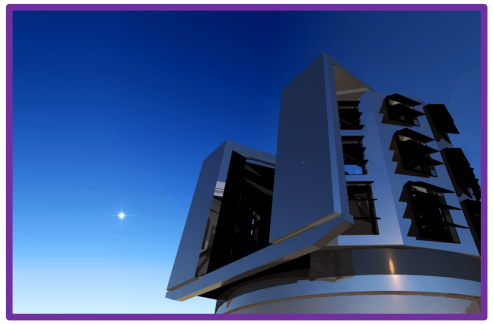
WEAK LENSING EXPERIMENTS

KIDS

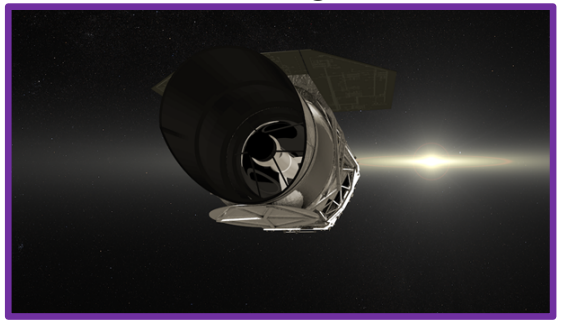
DES

HSC

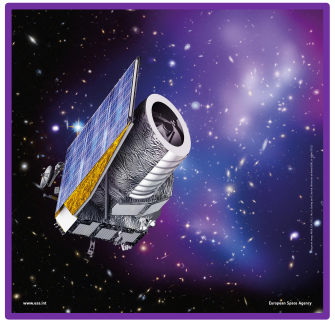
LSST



WFIRST

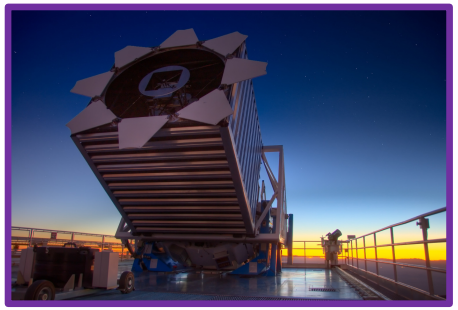


EUCLID



COMPLEMENTARITY, SYNERGY: large scale structures, CMB

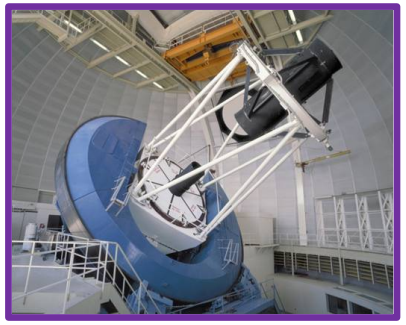
SDSS



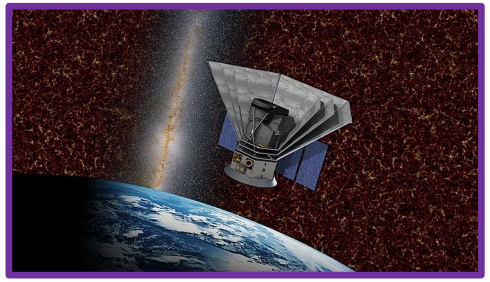
Planck

SPT

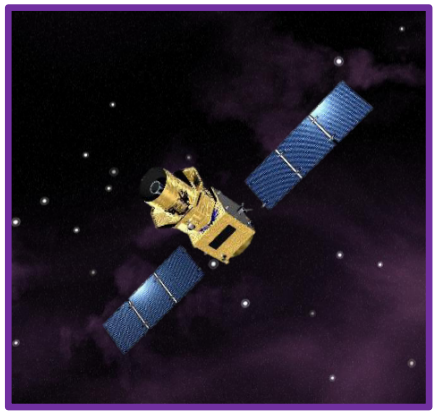
DESI



SPHEREx



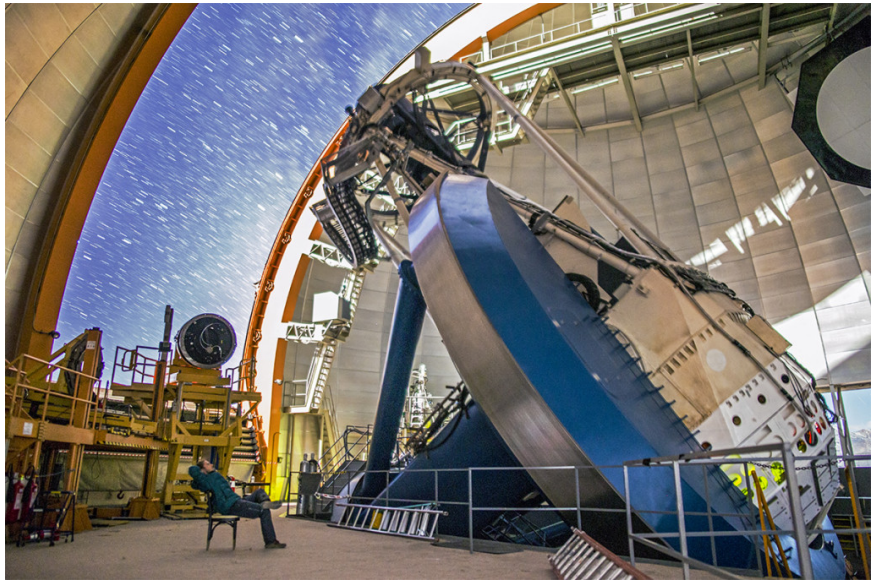
Litebird



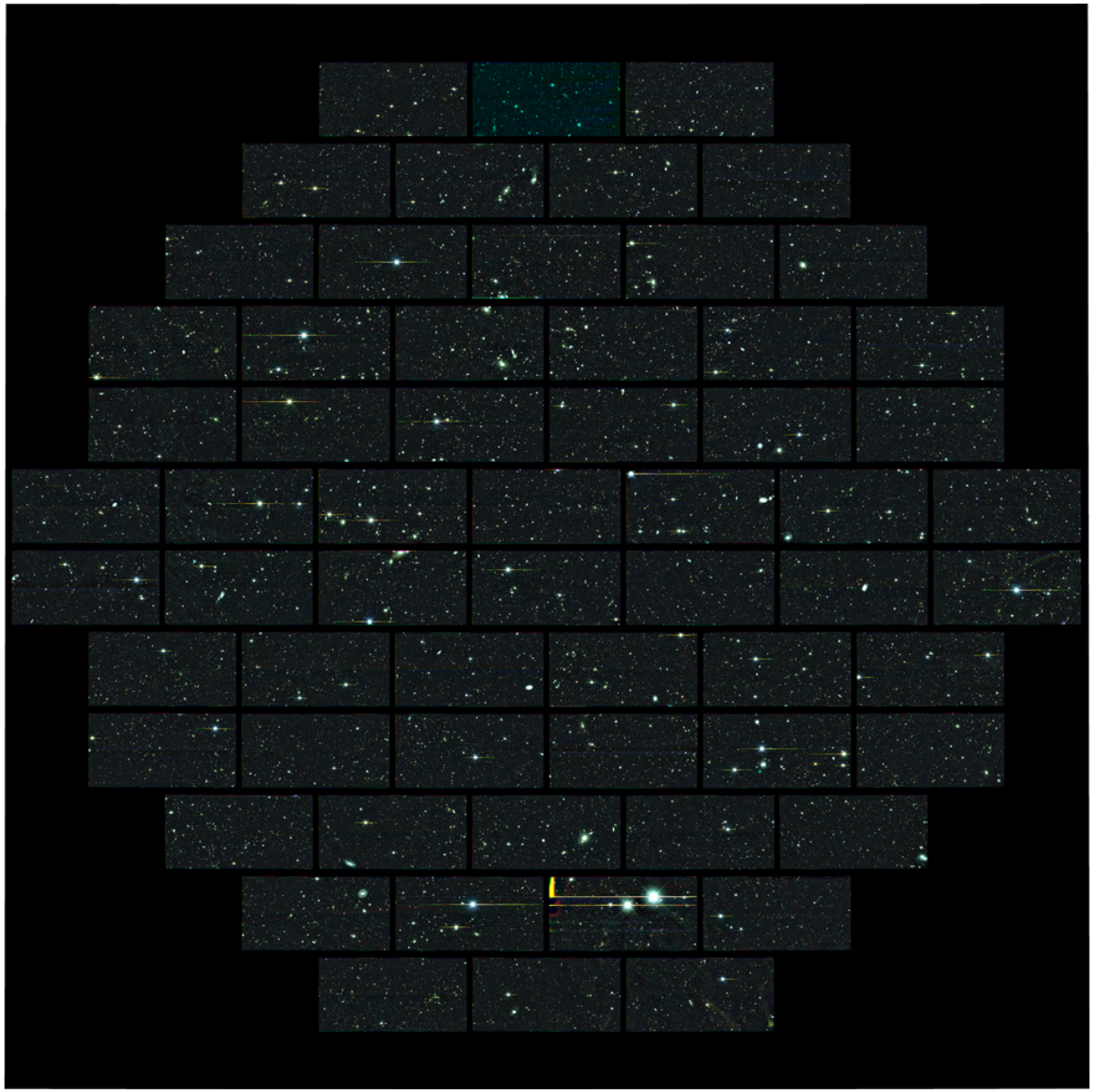
The Dark Energy Survey

- DECam at the Blanco-4m telescope (CTIO)
- 6 years survey: 2013-2019
- 5 optical filters
- ~400 scientists

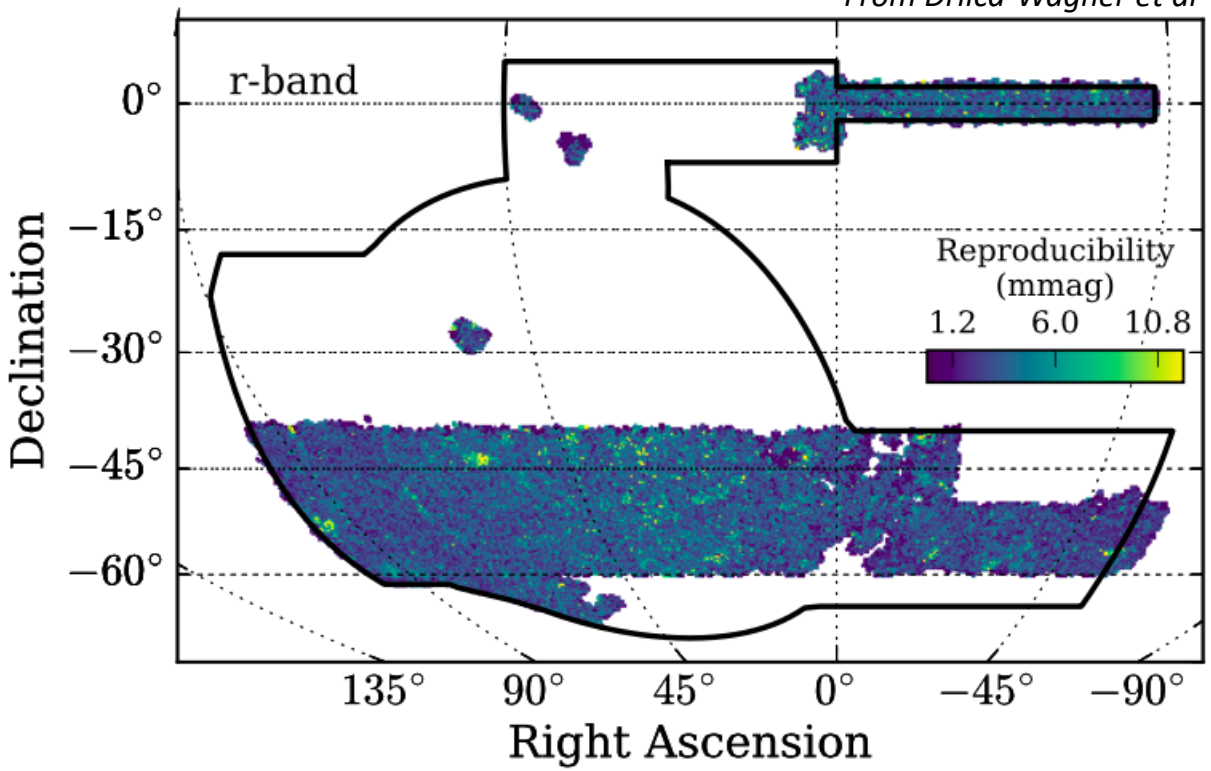
From T. Abbott and NOAO/AURA/NSF



DES collaboration

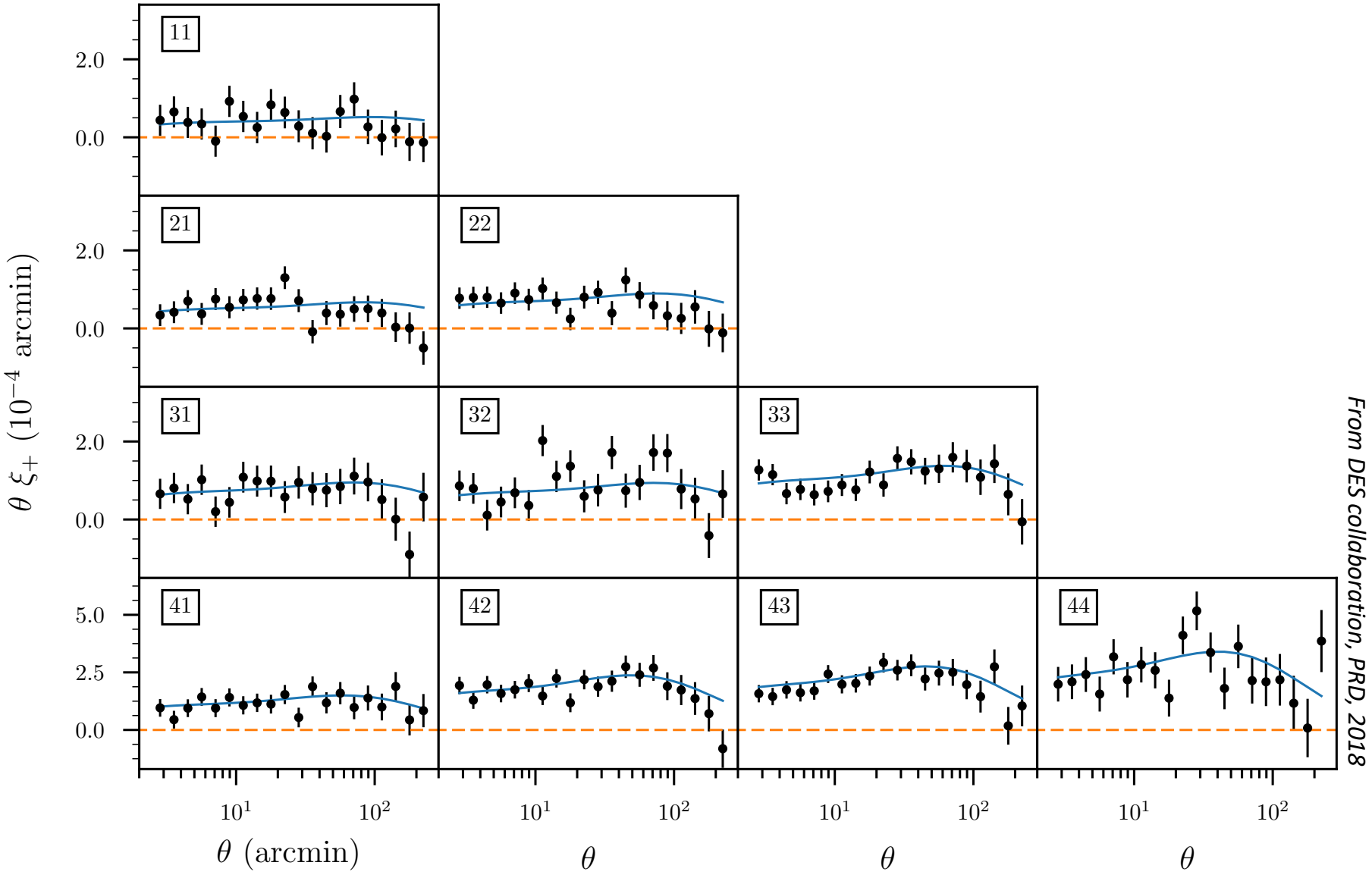


From Drlica-Wagner et al



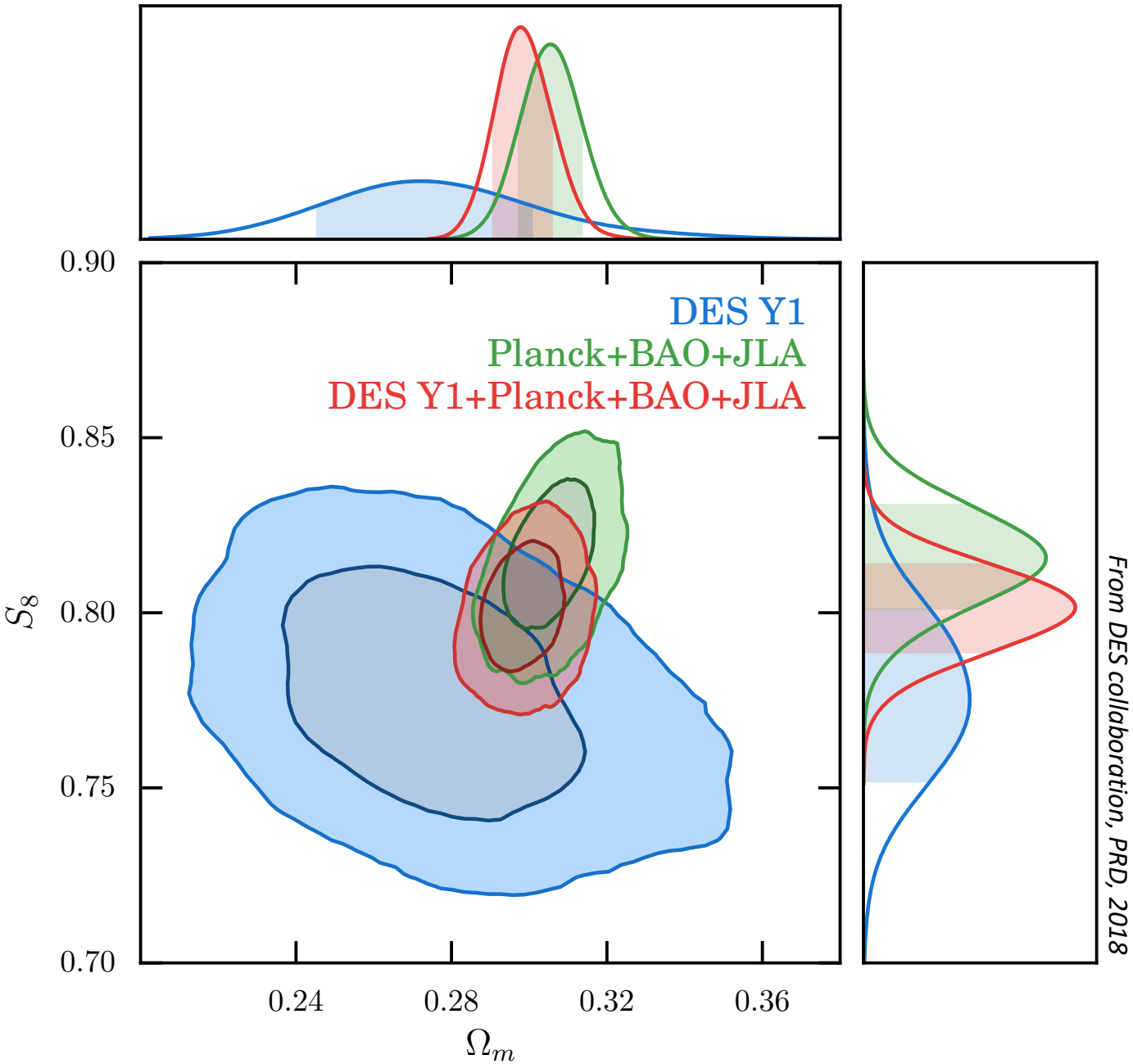
Dark energy with DES 1st year of observation data

DES collaboration, Phys. Rev. D 98, 043526 (2018)



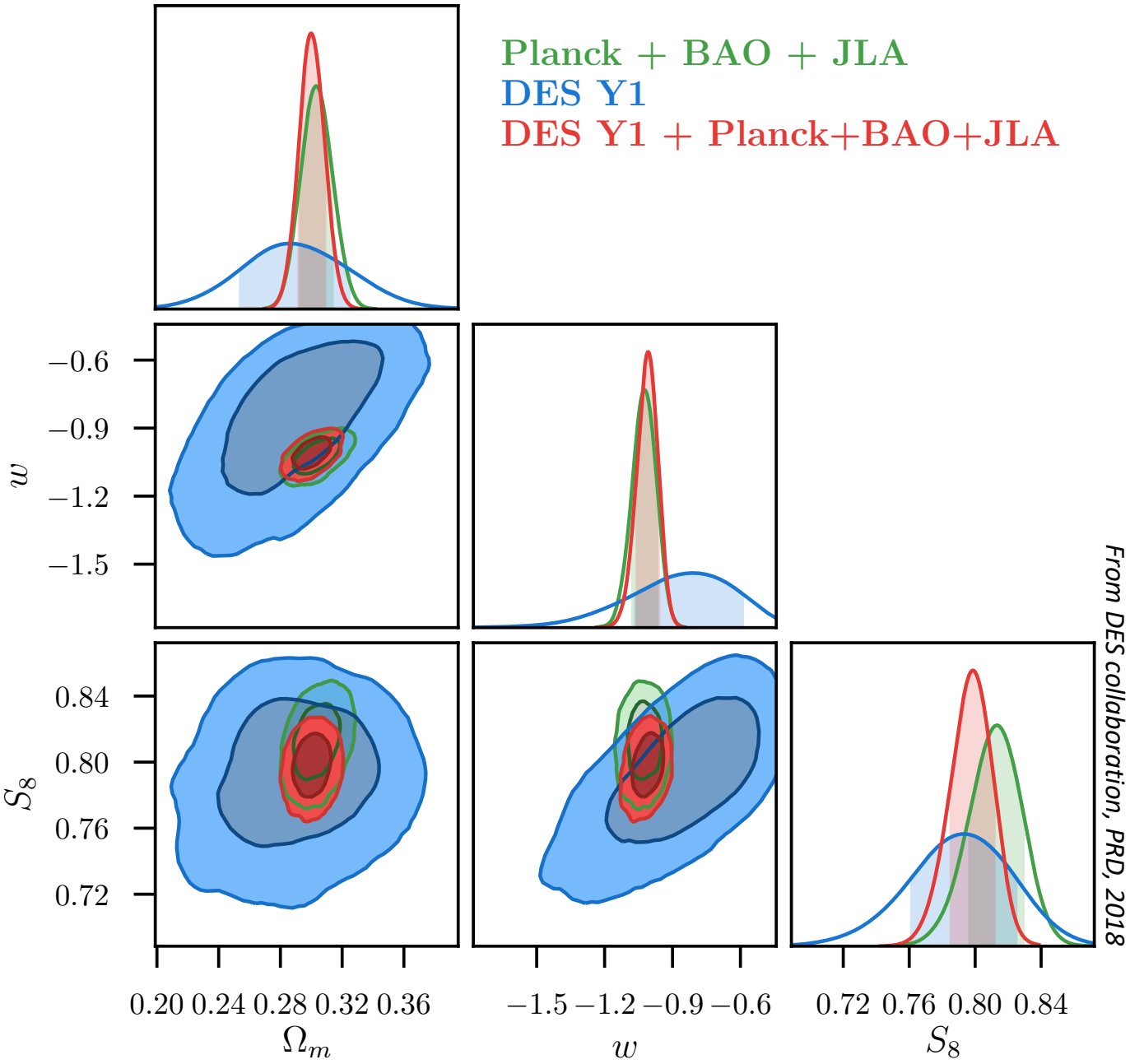
From DES collaboration, PRD, 2018

DES Y1 and ΛCDM model



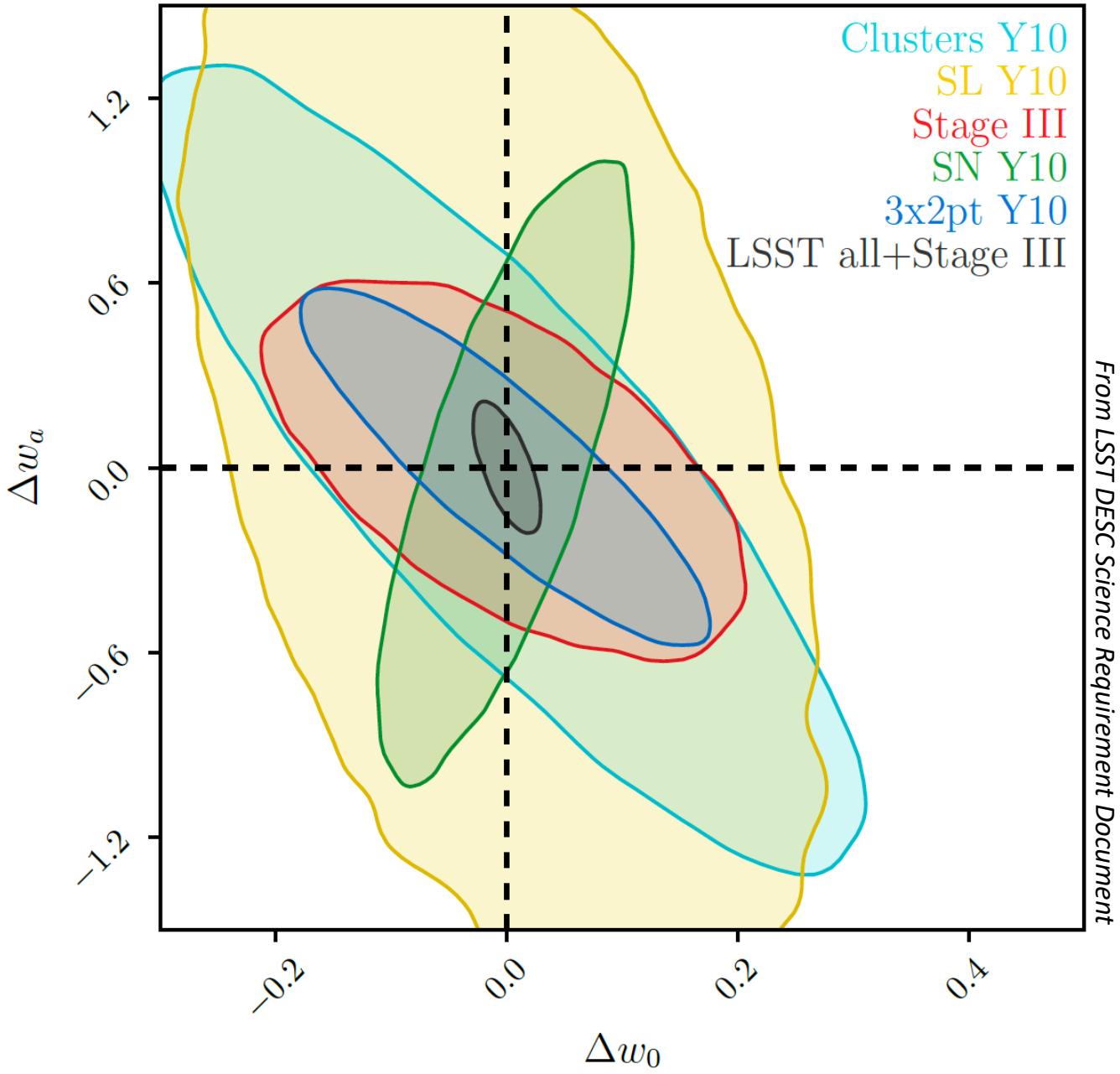
From DES collaboration, PRD, 2018

DES Y1 and wCDM model



From DES collaboration, PRD, 2018

In the future: example of 10 years of LSST and combining observables



From LSST DESC Science Requirement Document

Testing gravity on cosmological scales

Results with weak lensing

Phenomenological tests of gravity with cosmic shear

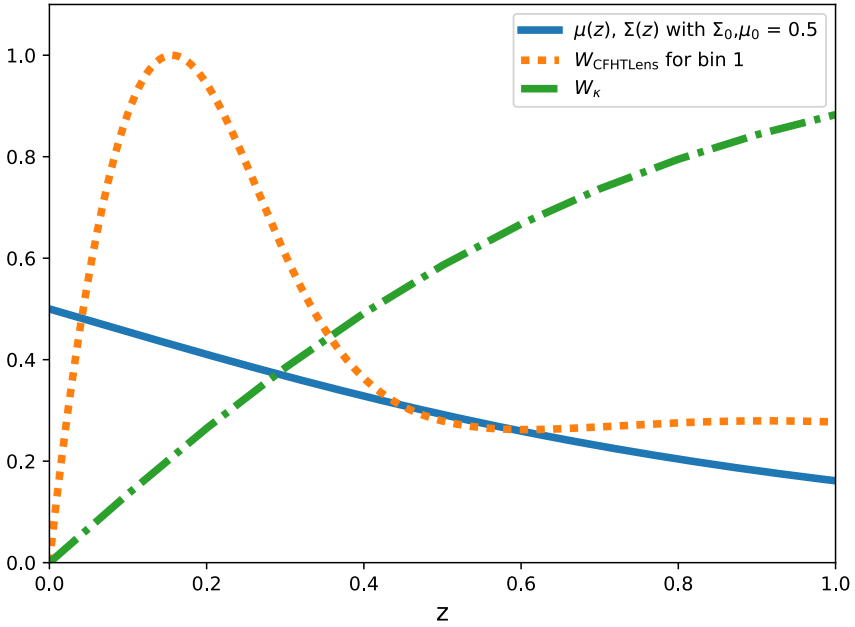
Ferté, Kirk, Liddle, Zuntz, Phys. Rev. D 99, 083512 (2019)

$$k^2\psi = -4\pi G a^2 (1 + \mu(a,k))\rho\delta$$

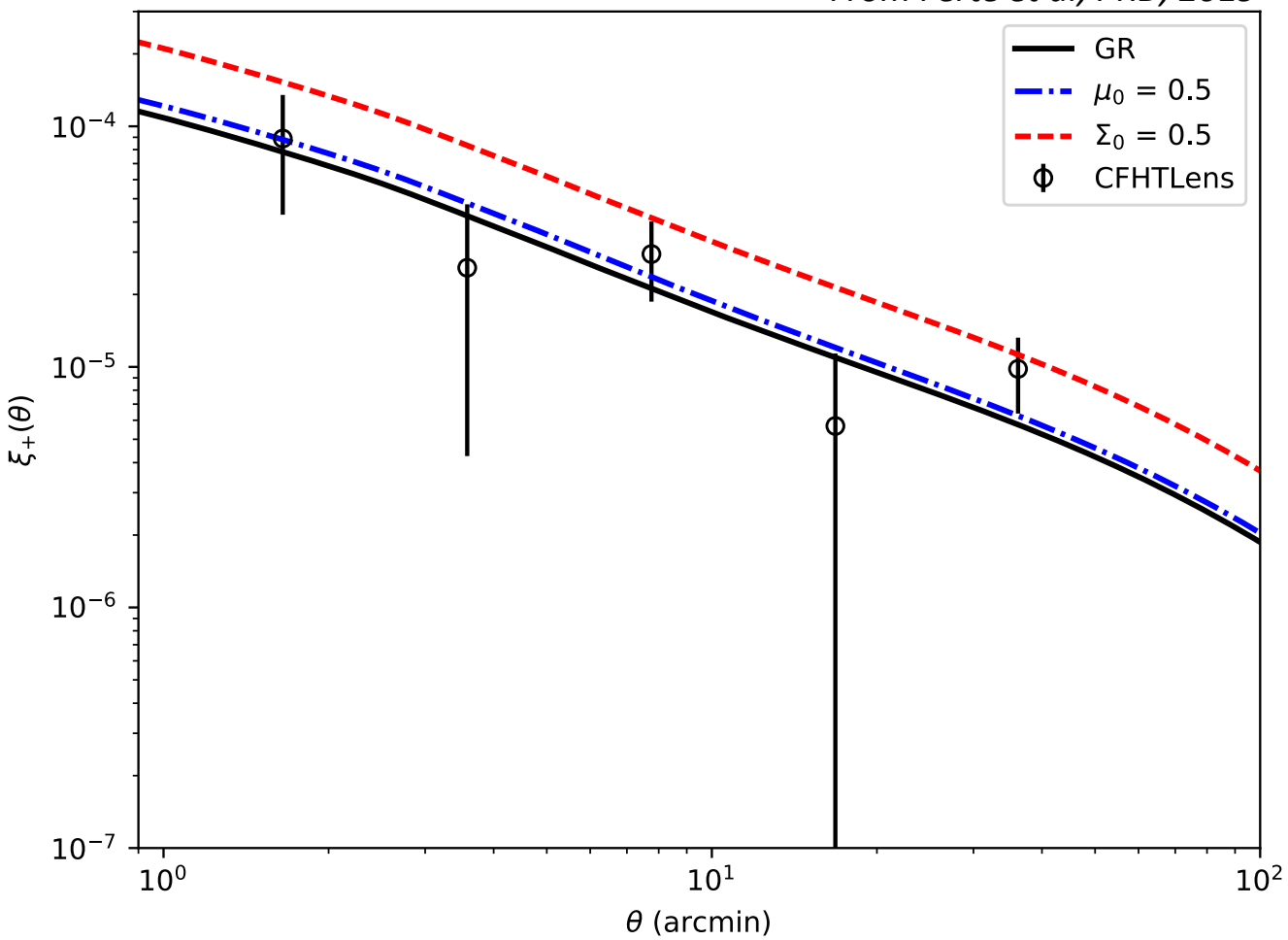
$$k^2(\psi + \phi) = -8\pi G a^2 (1 + \Sigma(a,k))\rho\delta$$

Time evolution as dark energy:

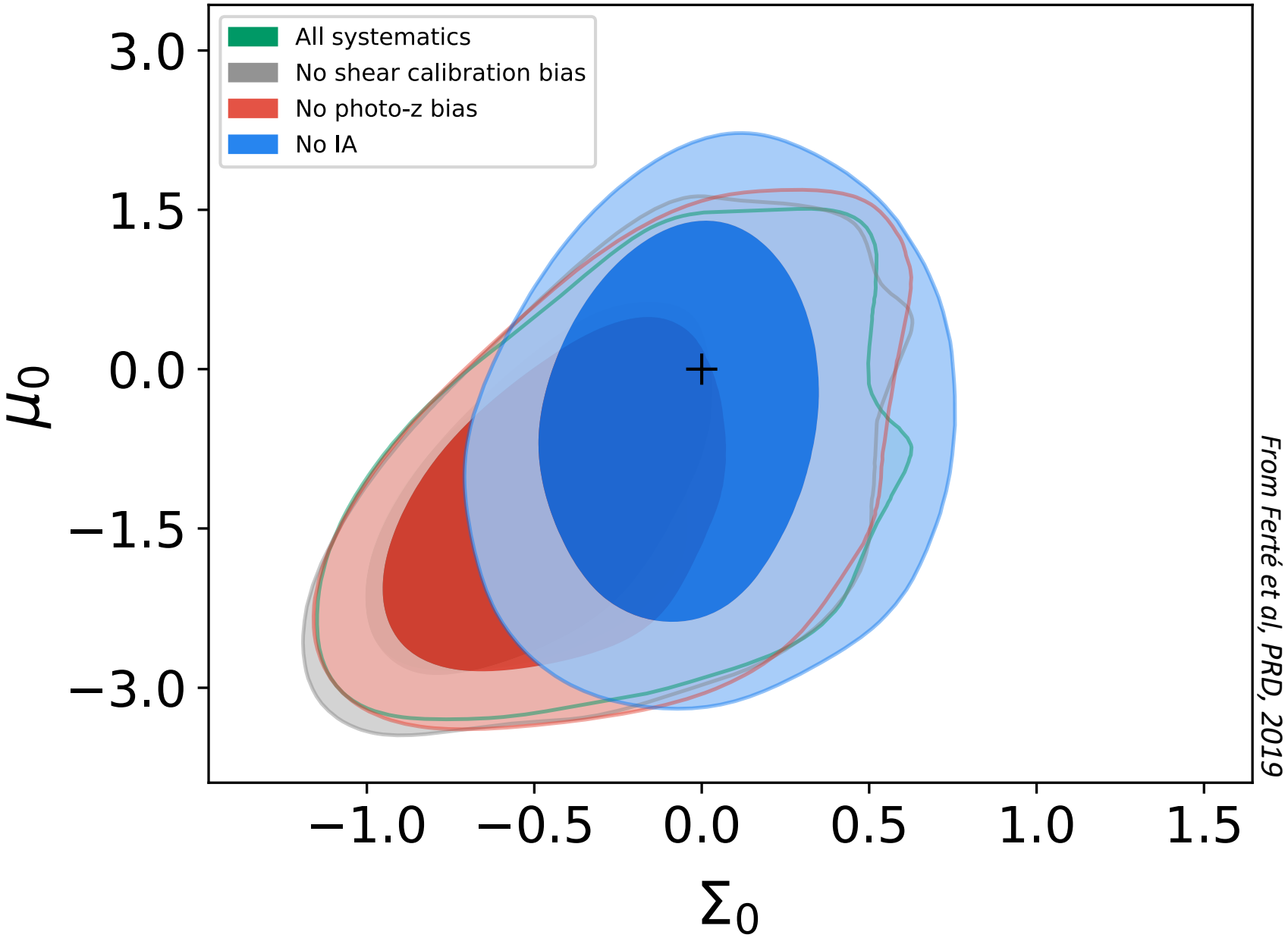
$$\mu(z) = \mu_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda}, \quad \Sigma(z) = \Sigma_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda}$$



From Ferté et al, PRD, 2019

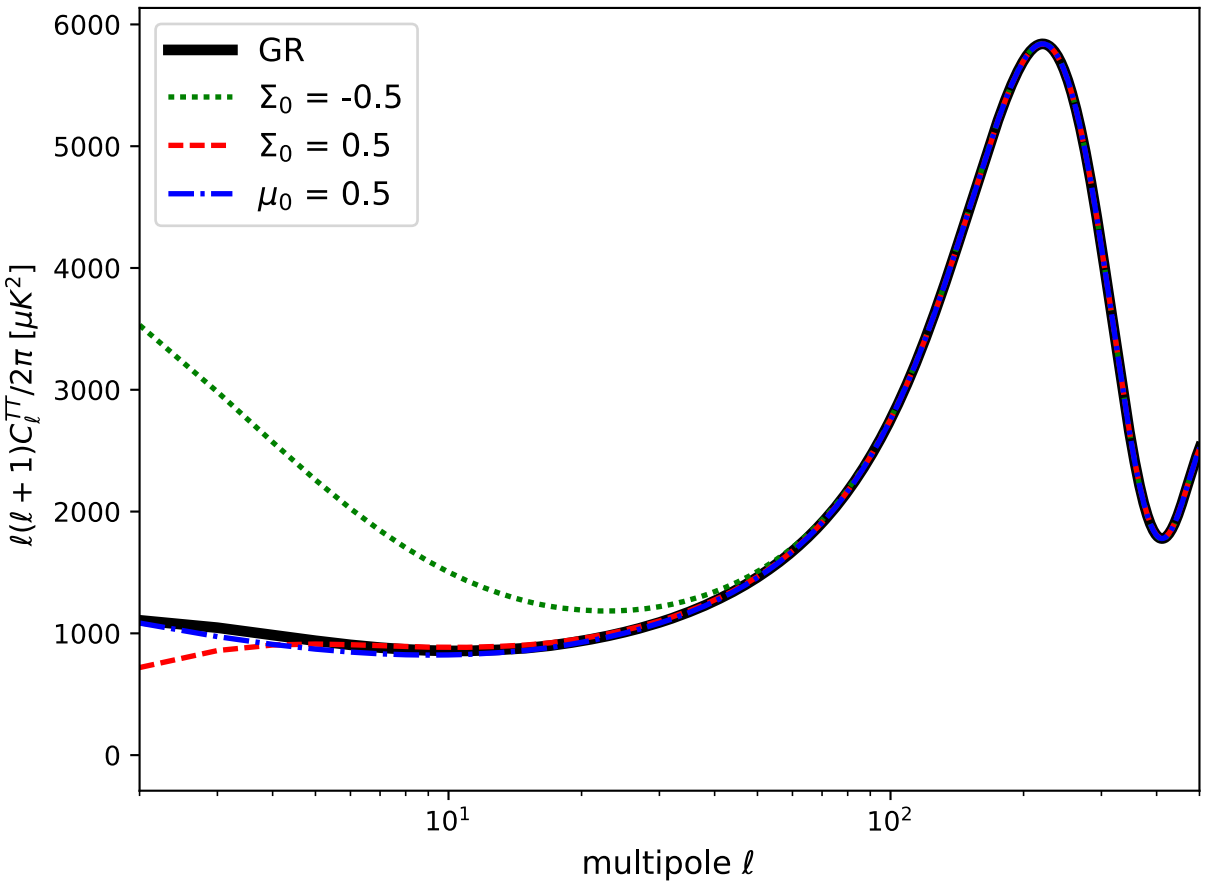


Impact of systematics

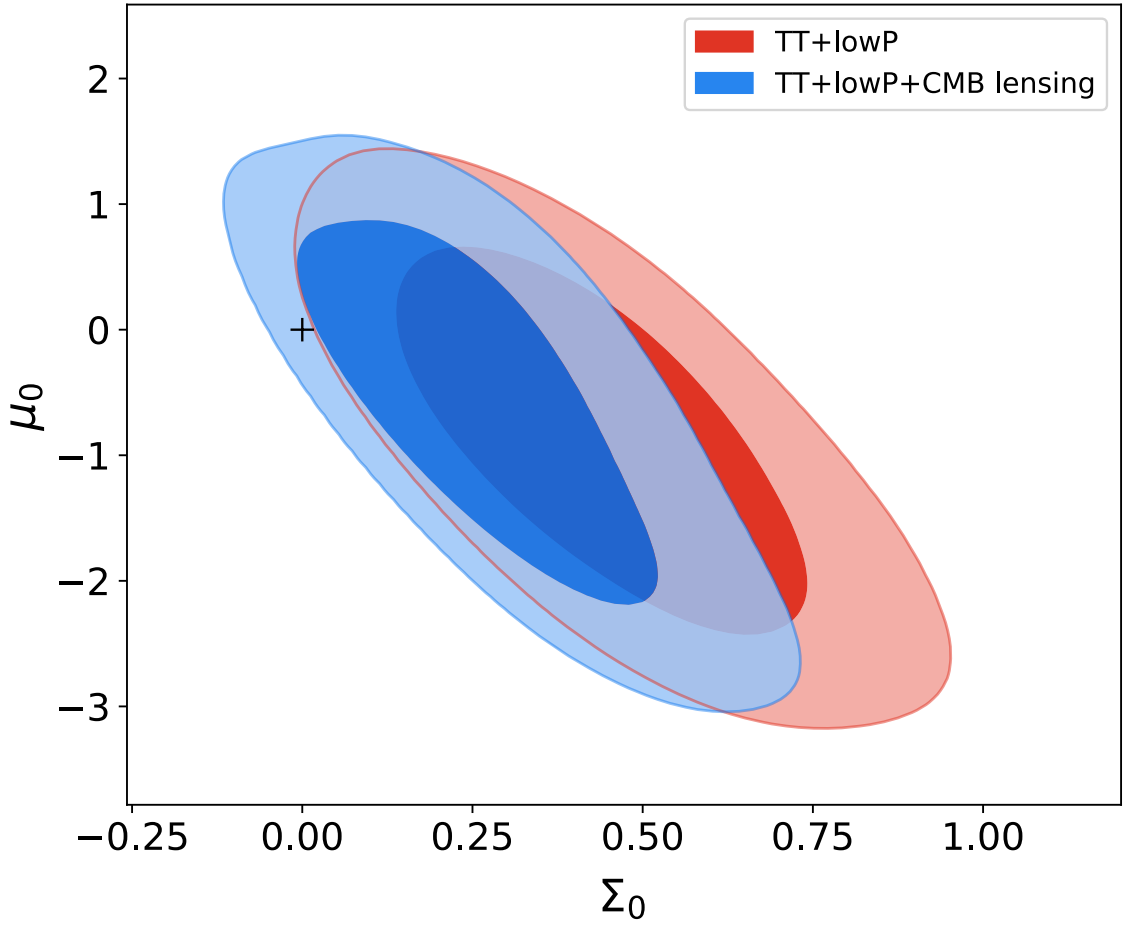


From Ferté et al, PRD, 2019

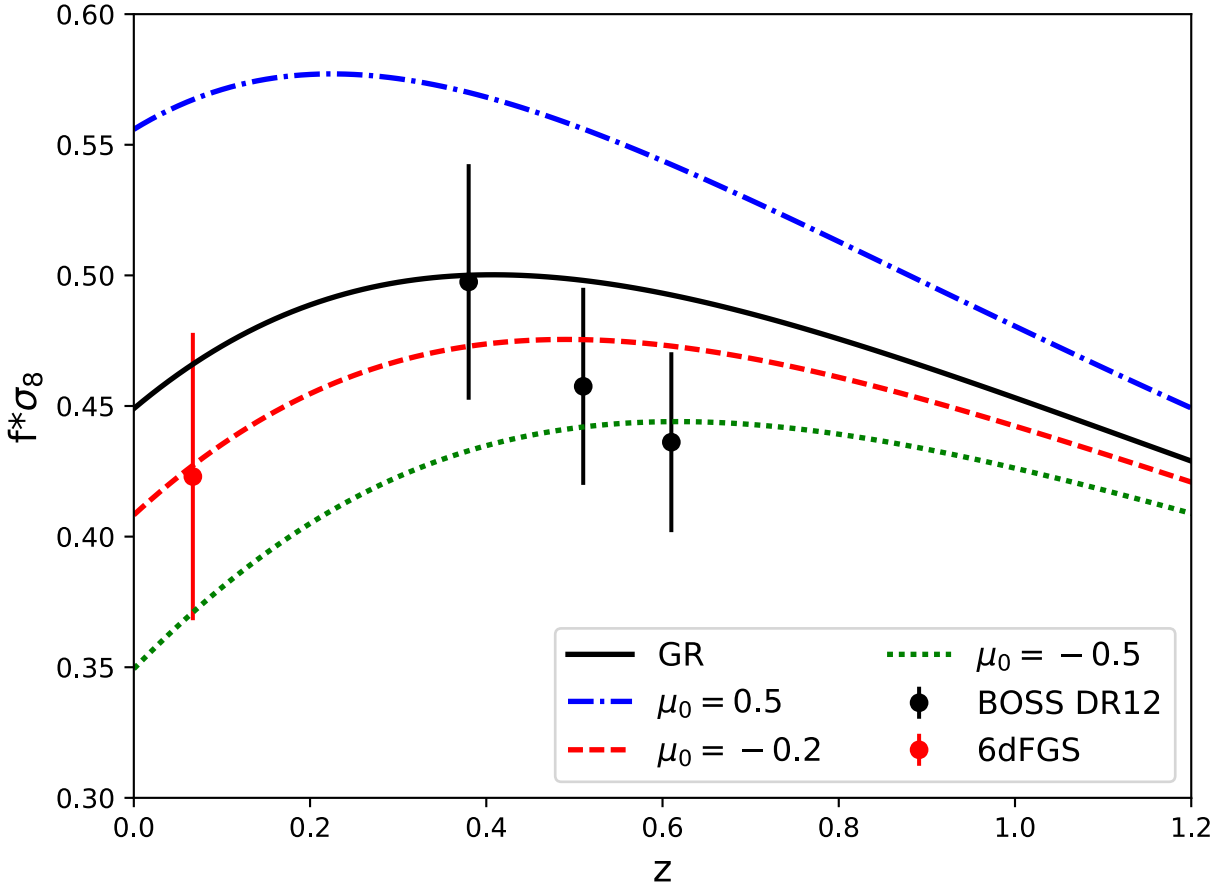
Testing gravity with CMB temperature and polarization



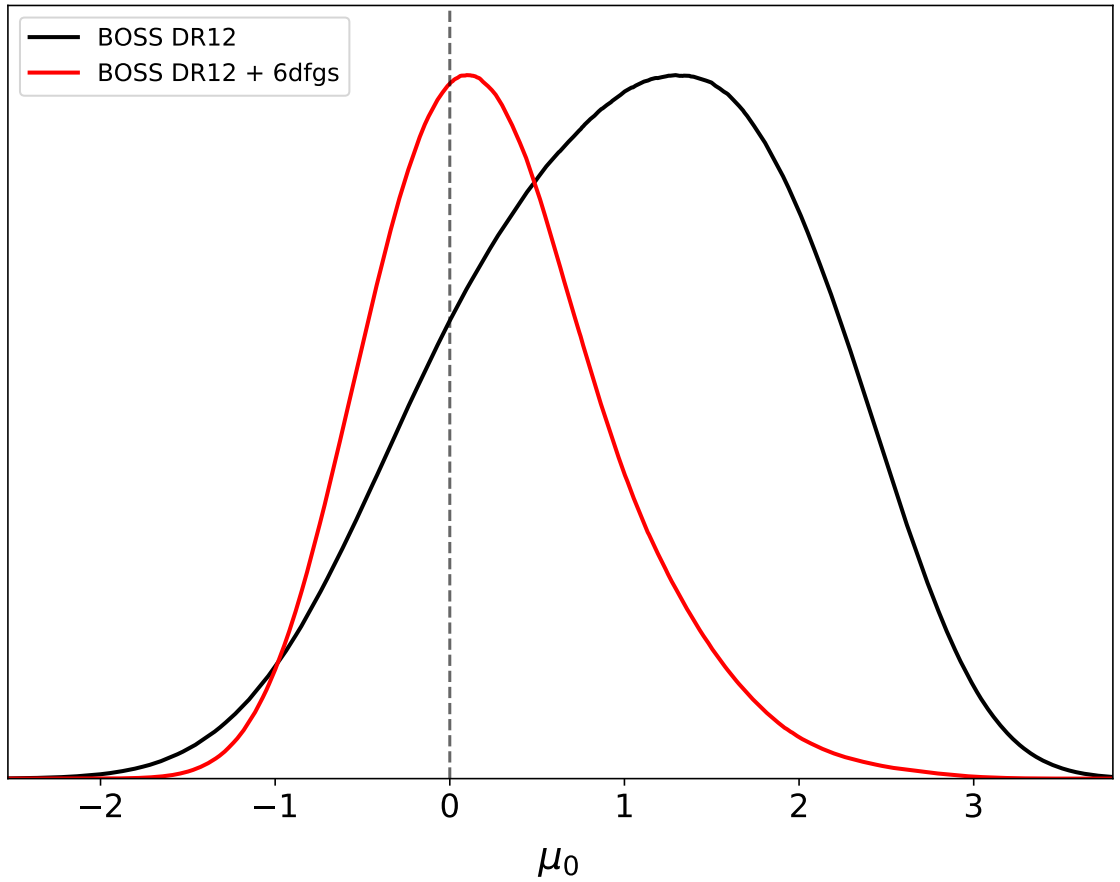
From Ferté et al, PRD, 2019



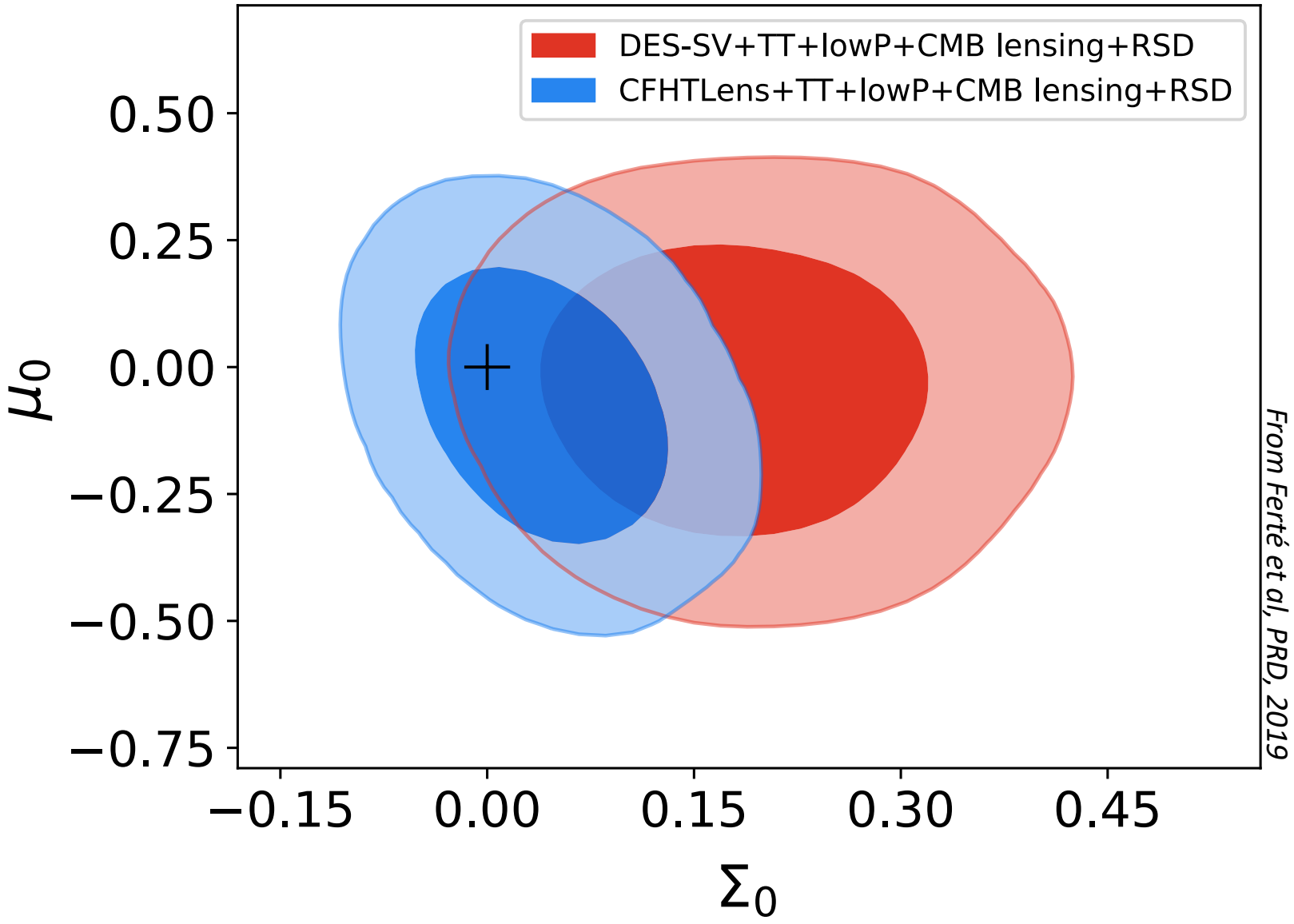
Testing gravity with redshift space distortion



From Ferté et al, Phys. Rev. D 99, 083512 2019

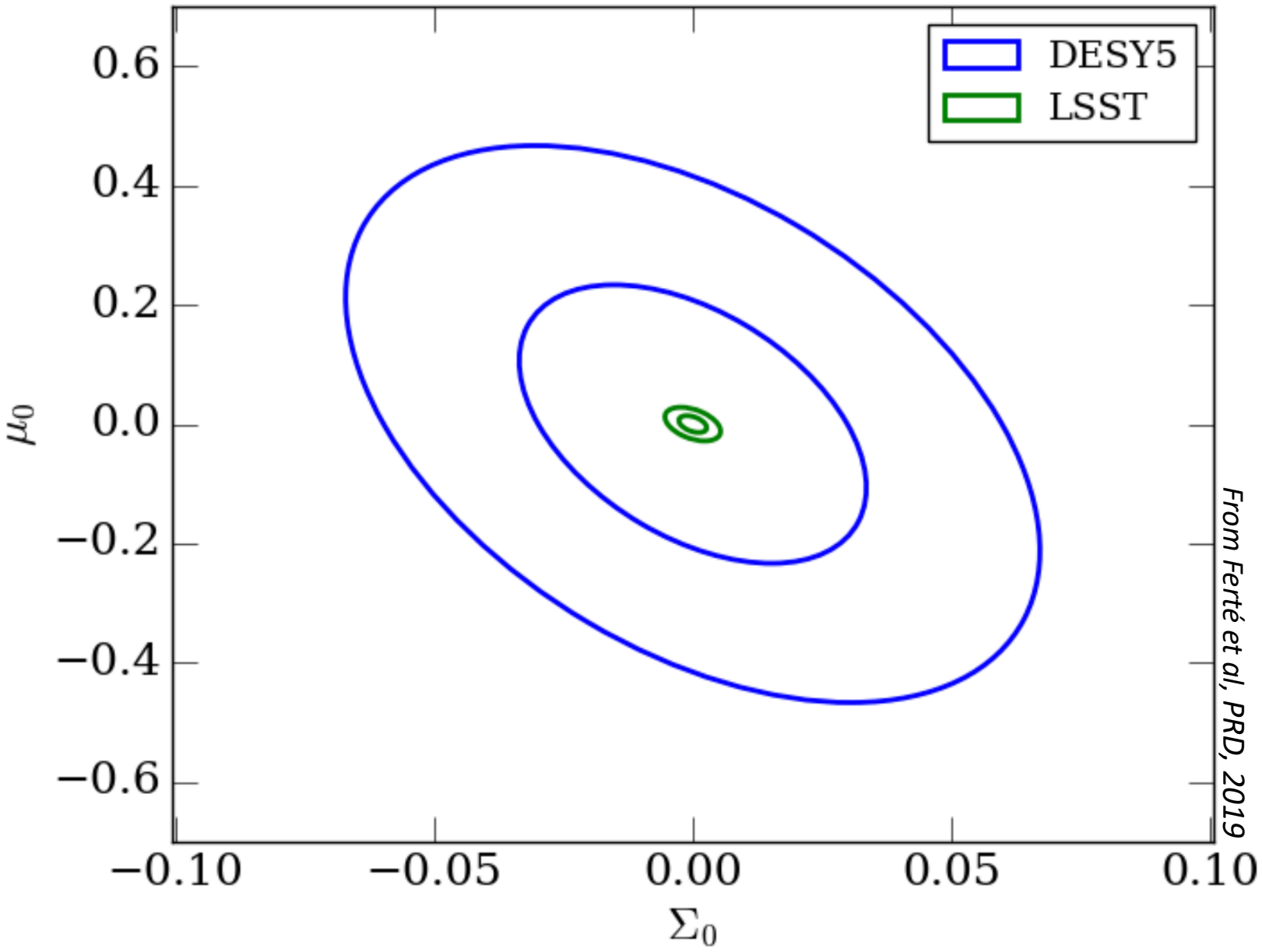


Testing gravity combining observables



From Ferté et al, PRD, 2019

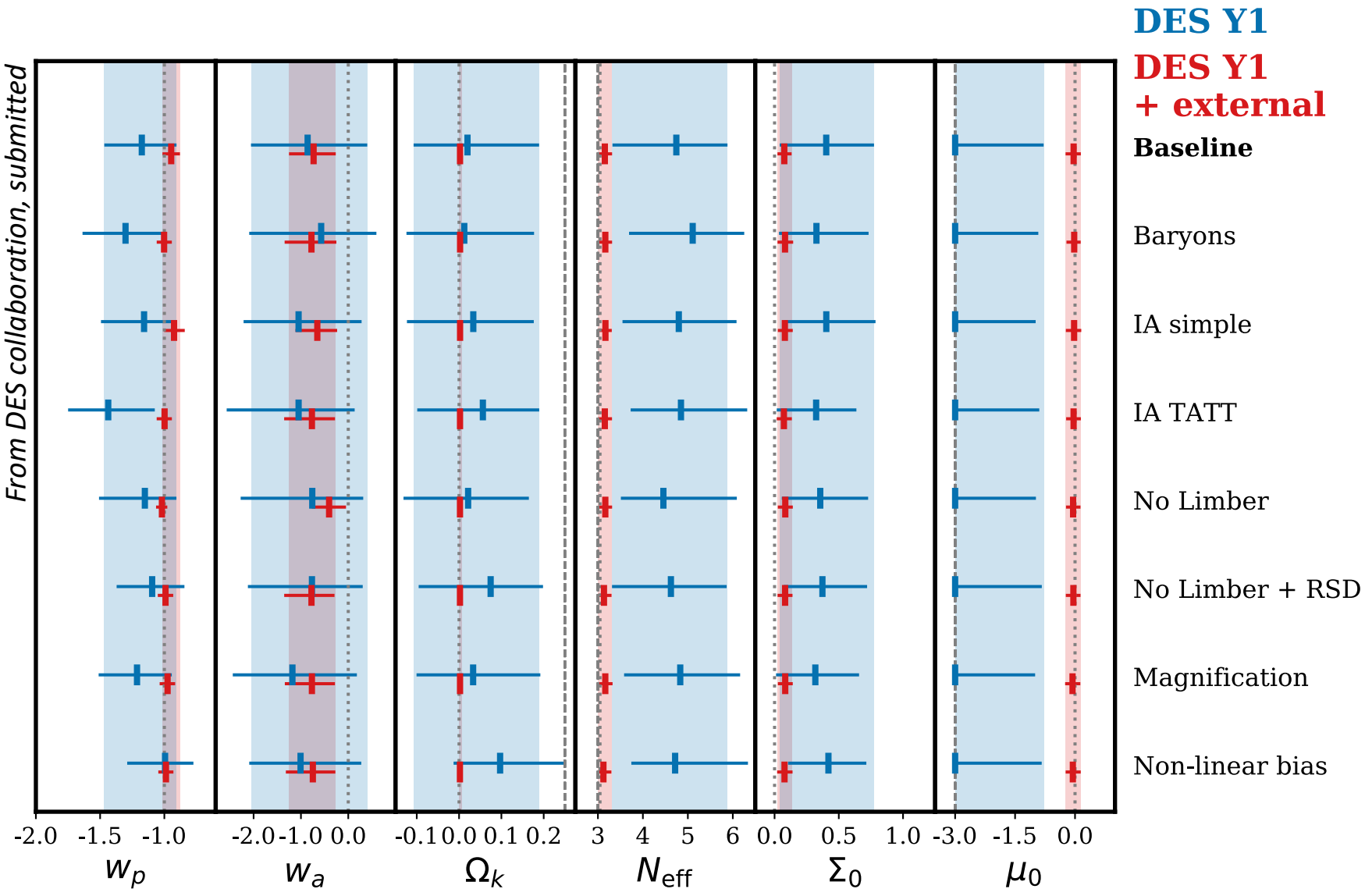
Forecasts for LSST

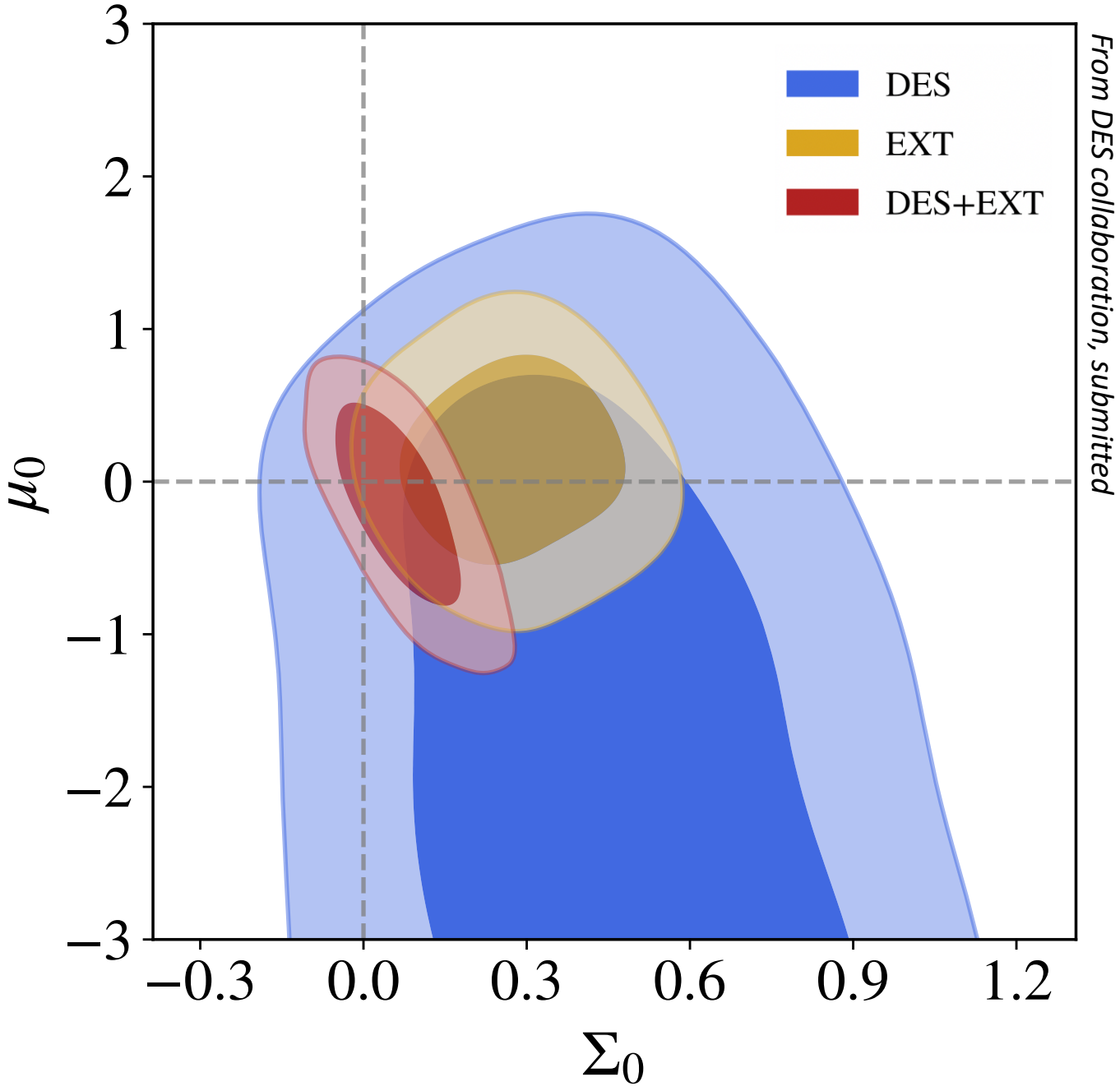


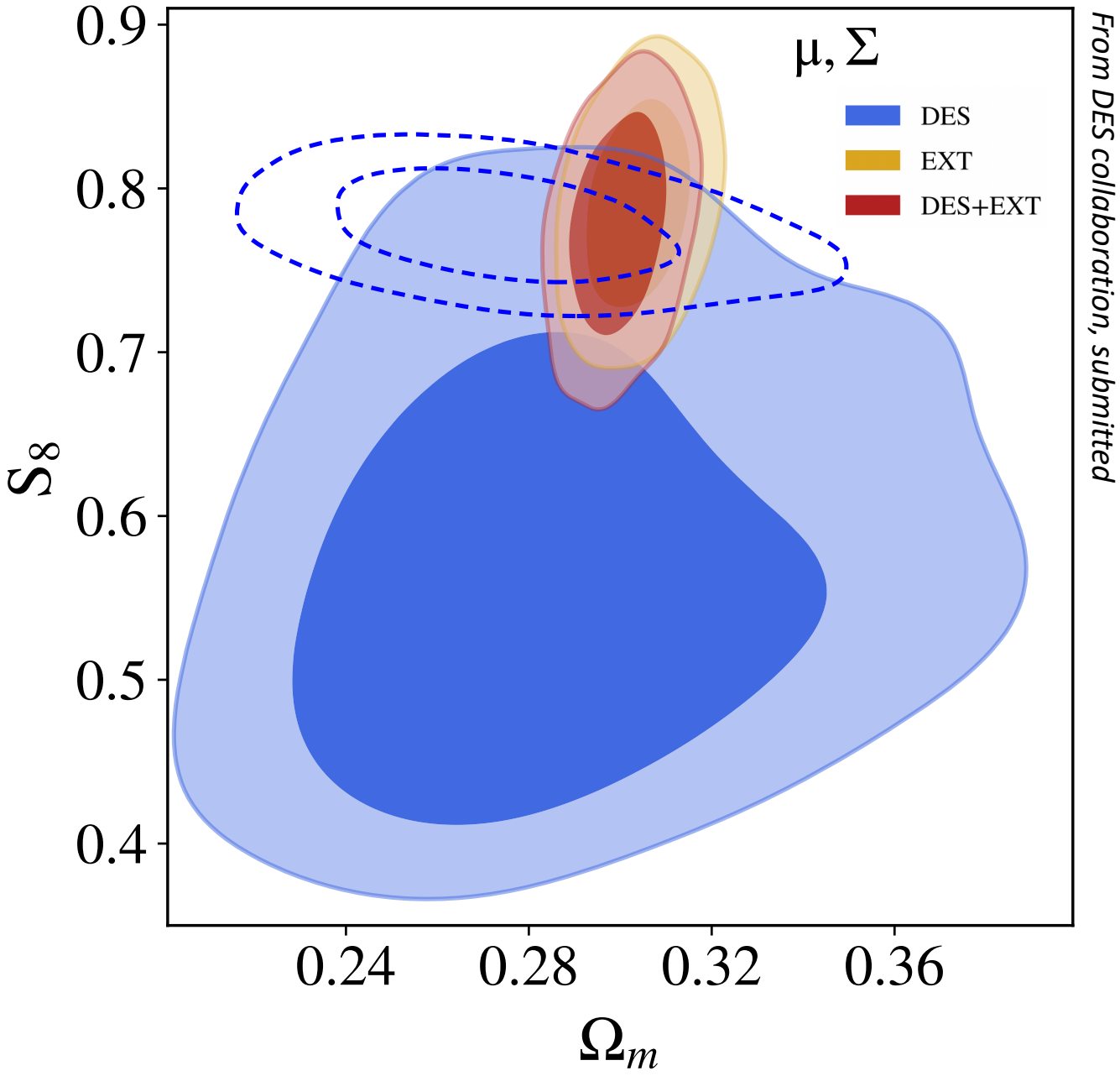
From Ferté et al, PRD, 2019

Testing gravity with DES 1st year of observation data

DES collaboration, accepted for publication to PRD, 2018



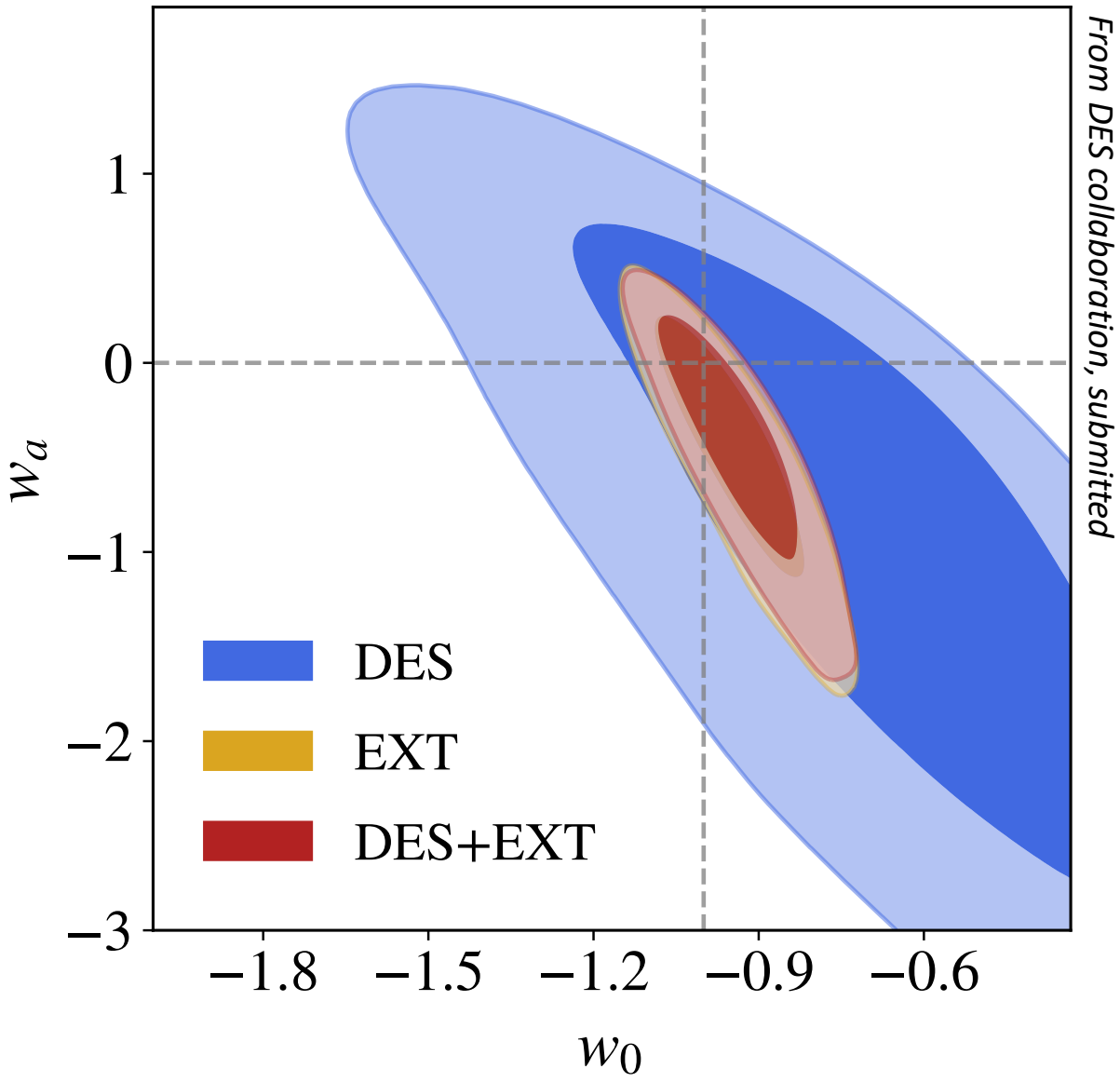

DES
EXT
DES+EXT
μ_0
Σ_0
3
2
1
0
−1
−2
−3
−0.3
0.0
0.3
0.6
0.9
1.2
From DES collaboration, submitted



From DES collaboration, submitted

Other extensions to LCDM model: a dynamical dark energy

DES collaboration, accepted for publication to PRD, 2018

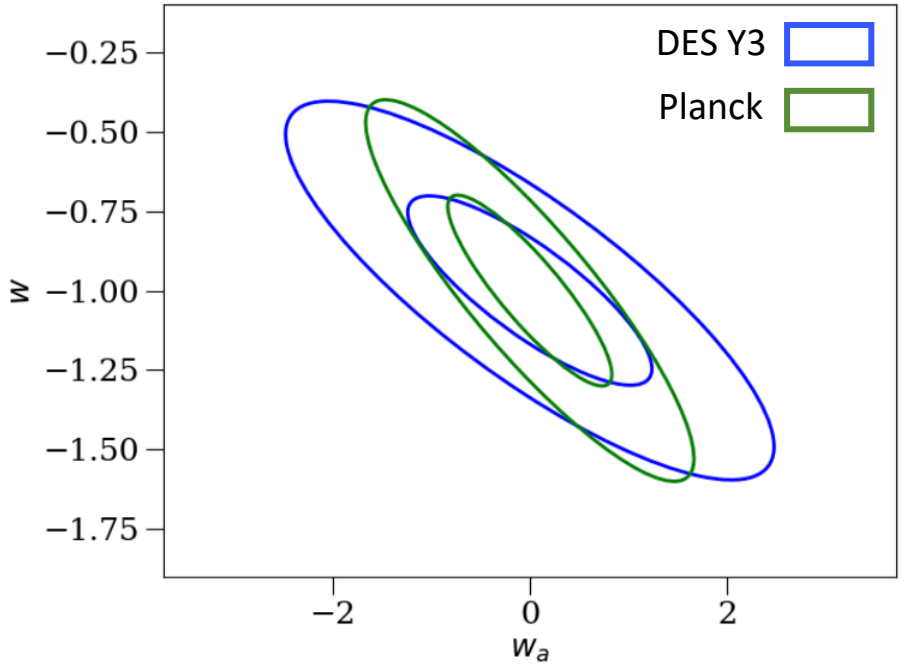


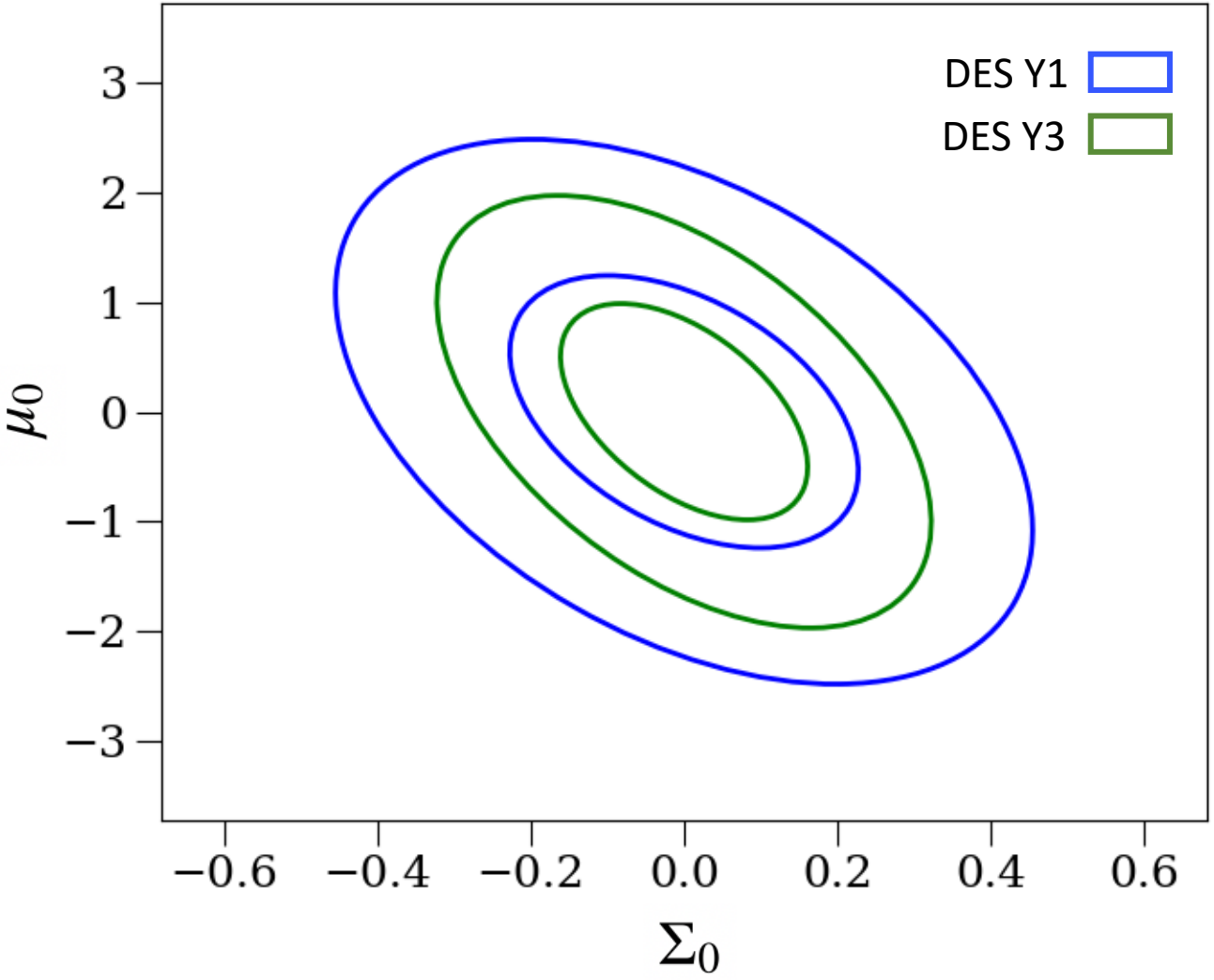
From DES collaboration, submitted

Dark Energy Survey 3 years of observation: work in progress

Extensions to ΛCDM model:

- Models and data sets to use
- Validation tests
- Analysis choices
- Actual analysis on the real DES Y3 data

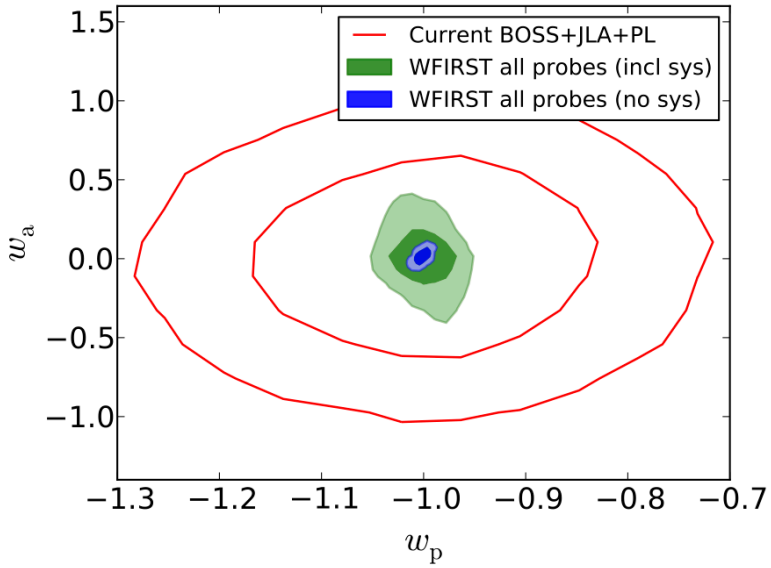


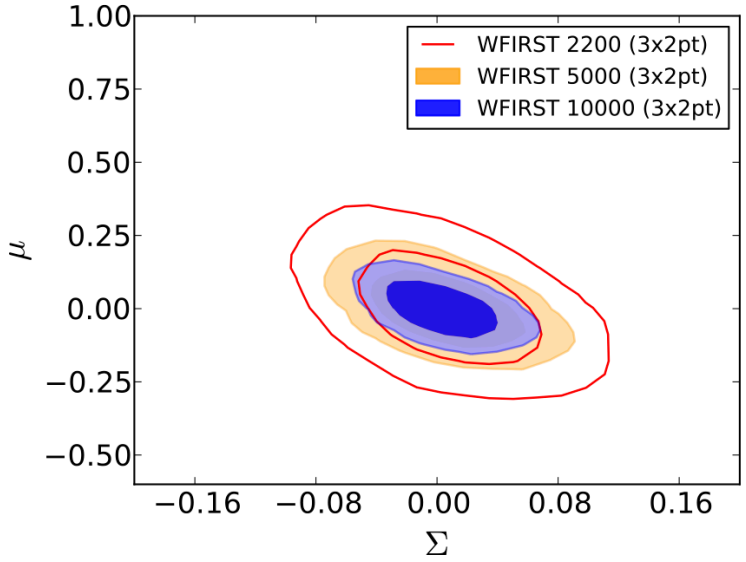


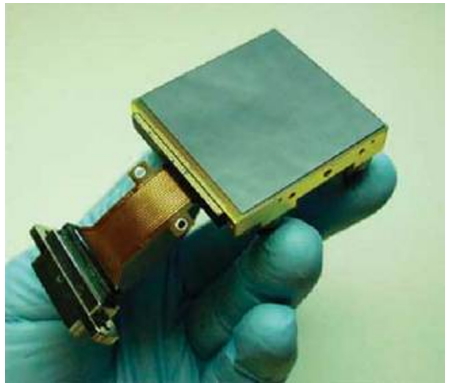
High precision weak lensing measurements

New instrumental challenges

Understanding detector effects: beyond first order effect



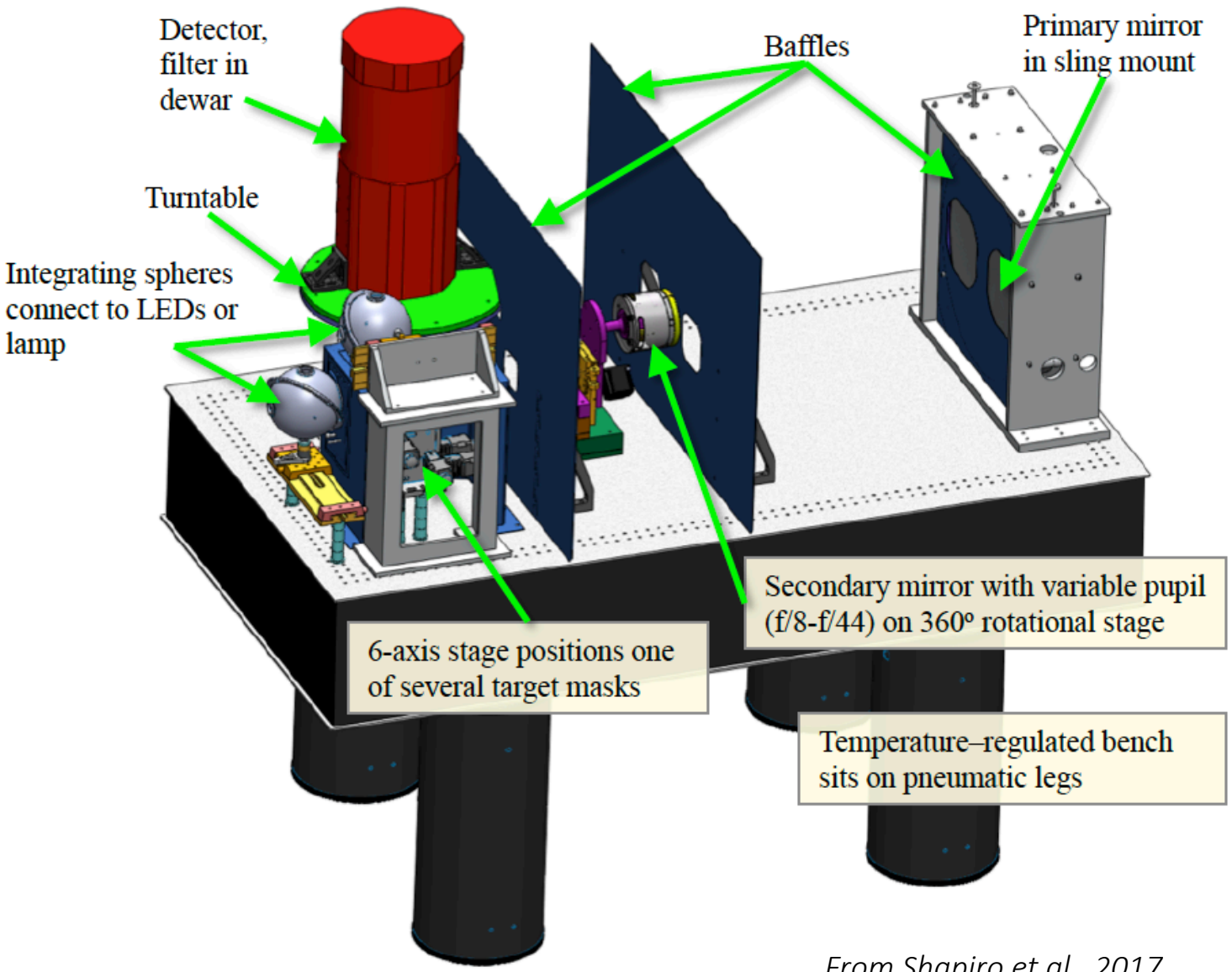




Effects to understand in new detector (CMOS) e.g.:

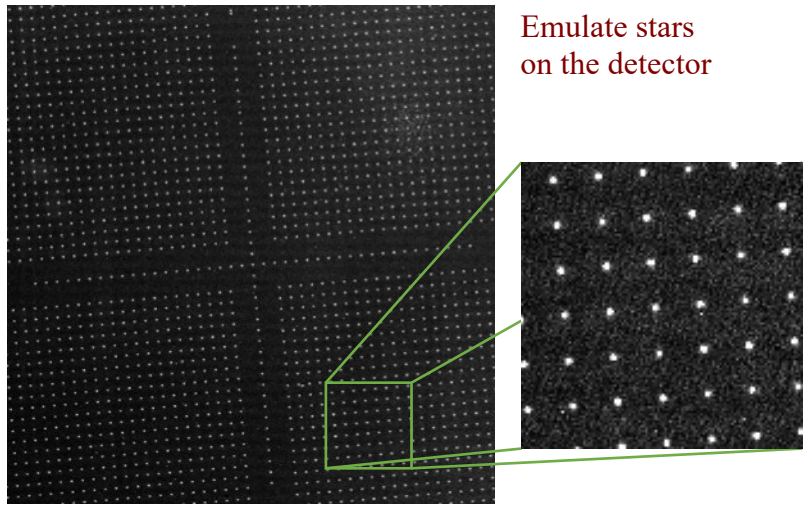
- Image persistent
- Non linearities

Precision Projector Laboratory: emulating astronomical observations in the lab



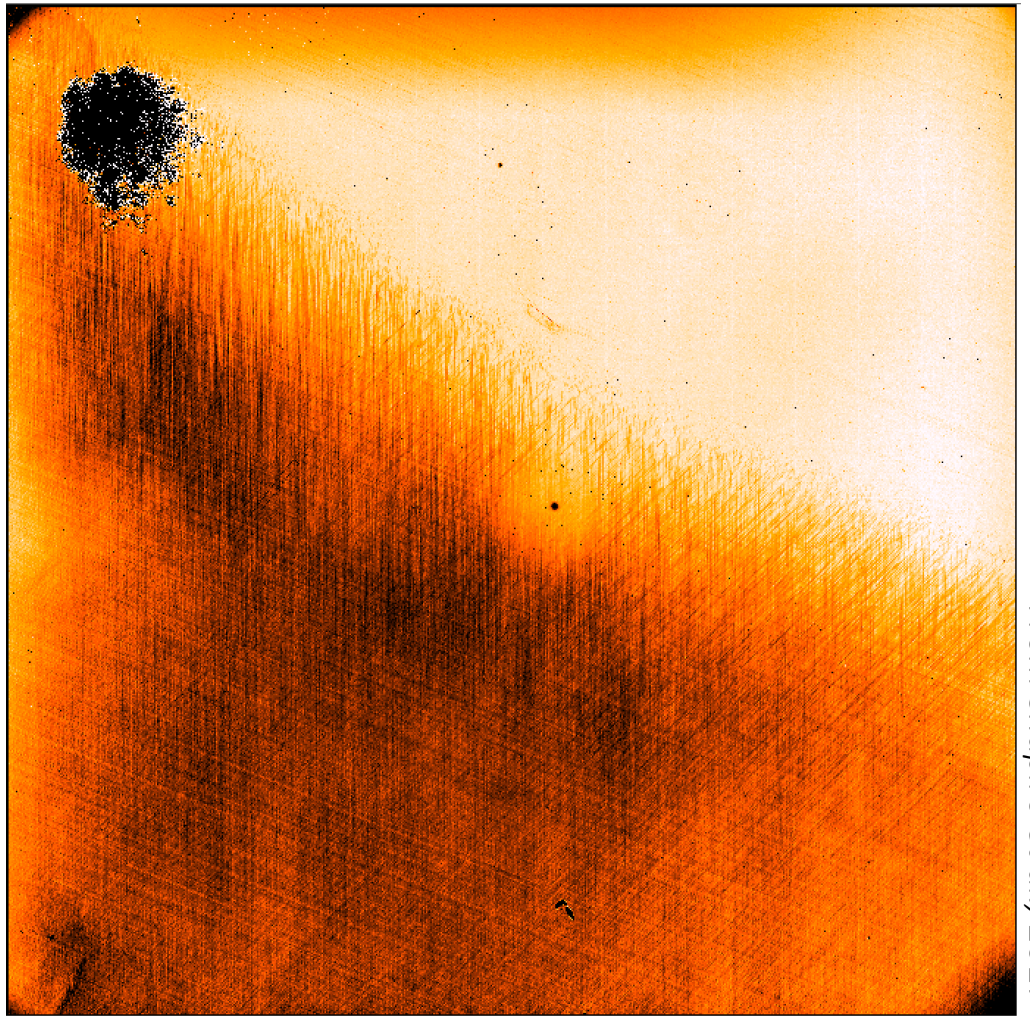
From Shapiro et al., 2017

e.g. for weak lensing:



Some effects studied at PPL

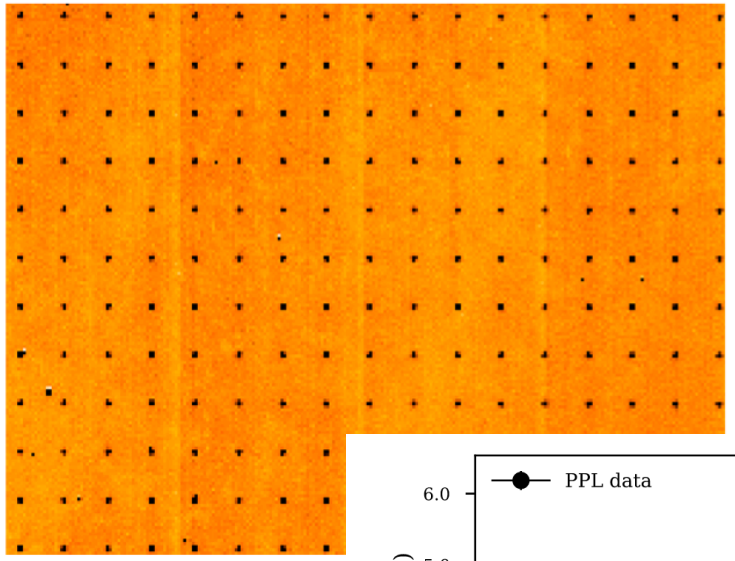
Cross hatch

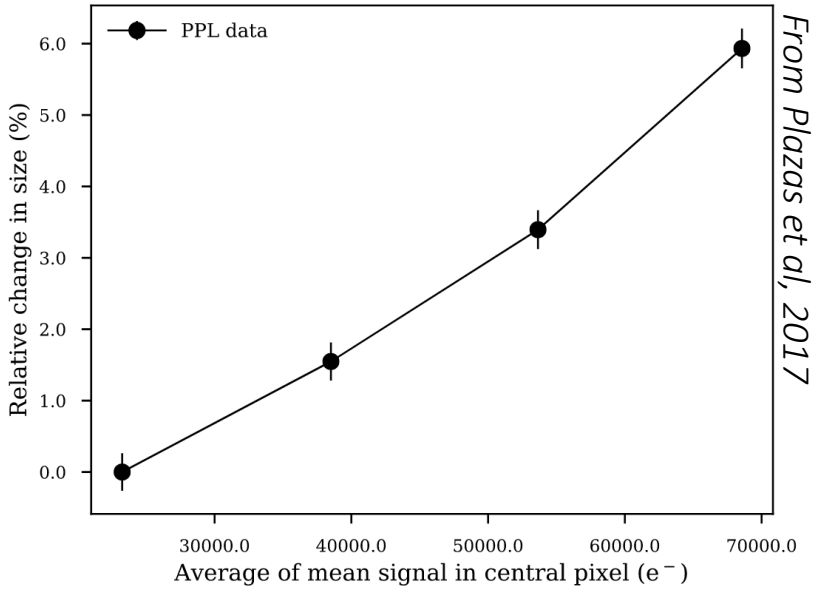


From Shapiro et al., 2017

Brighter-fatter effect

PPL “stars” (Euclid H2RG)

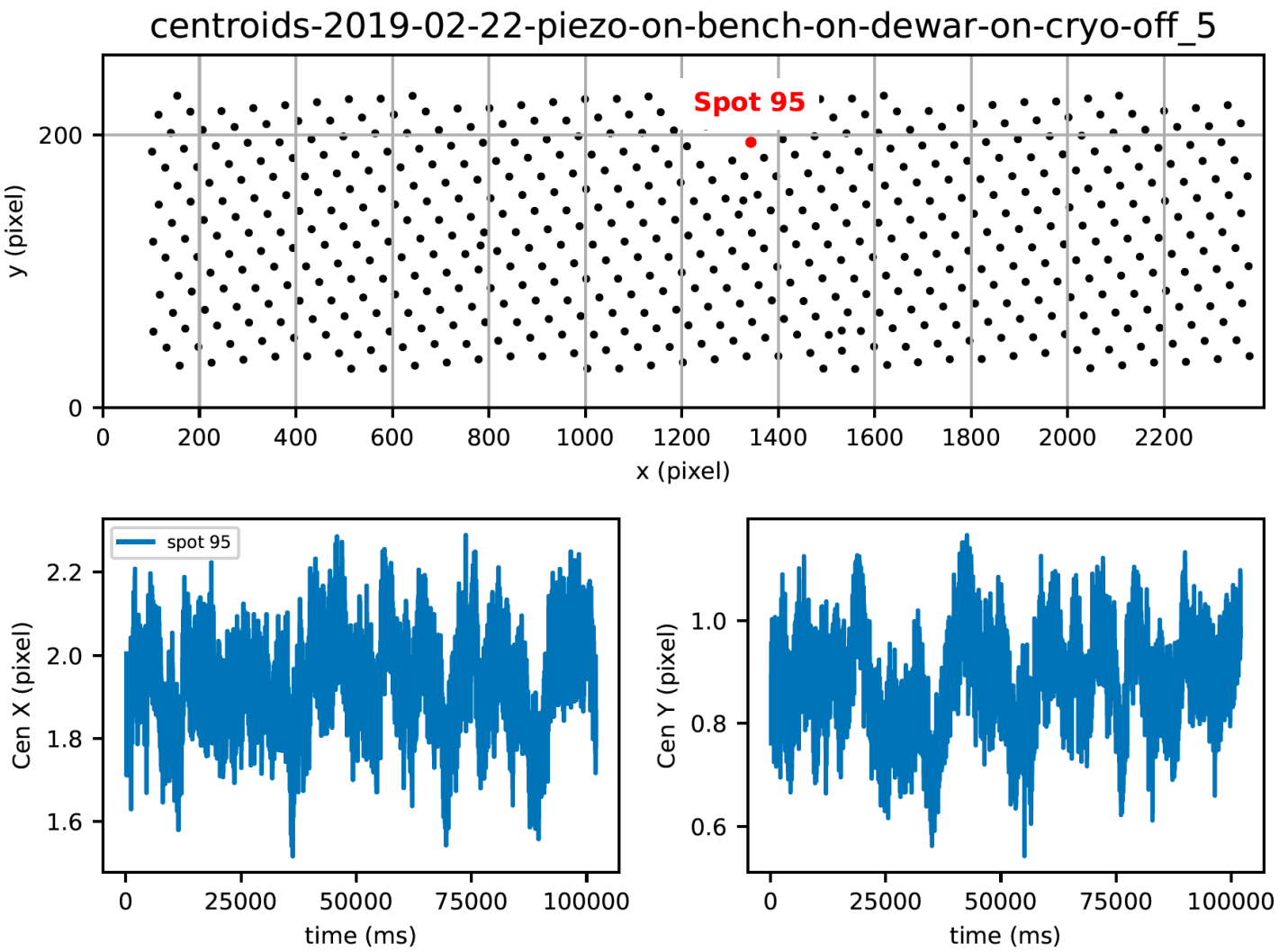


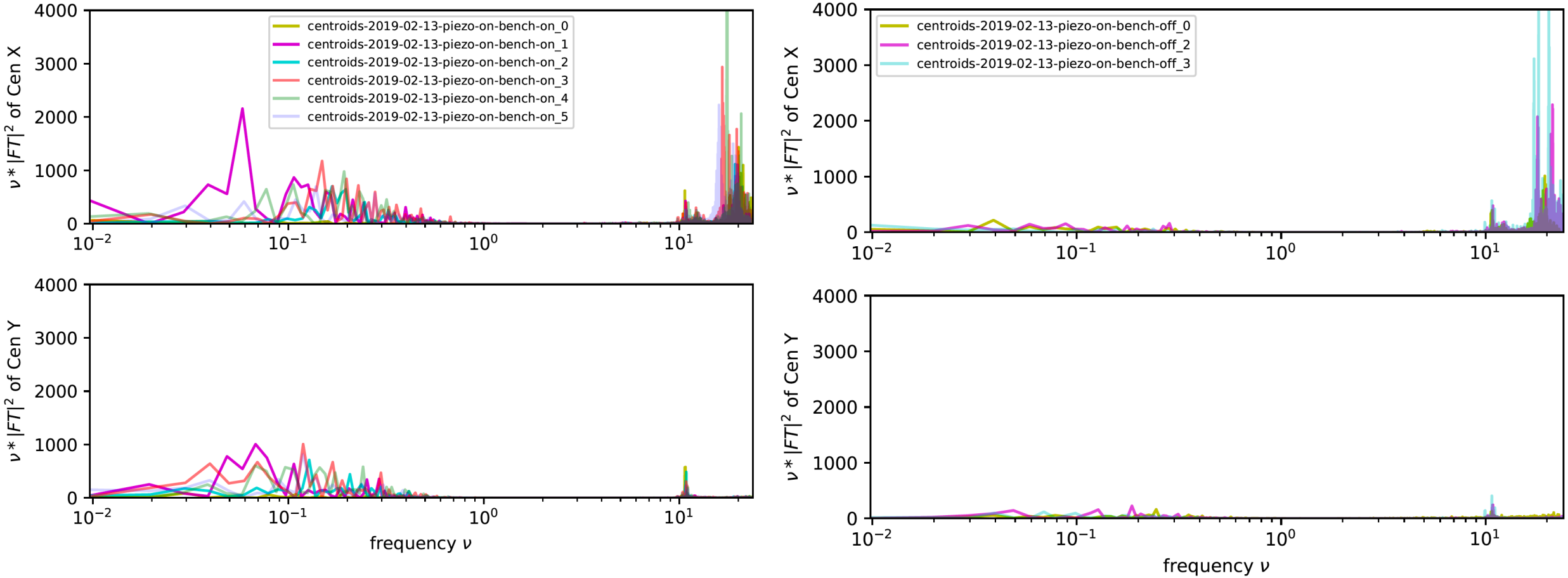


From Plazas et al, 2017

Characterizing the image motion

Centroid measured with different settings of the testbed elements:




centroids-2019-02-13-piezo-on-bench-on_0
centroids-2019-02-13-piezo-on-bench-on_1
centroids-2019-02-13-piezo-on-bench-on_2
centroids-2019-02-13-piezo-on-bench-on_3
centroids-2019-02-13-piezo-on-bench-on_4
centroids-2019-02-13-piezo-on-bench-on_5
centroids-2019-02-13-piezo-on-bench-off_0
centroids-2019-02-13-piezo-on-bench-off_2
centroids-2019-02-13-piezo-on-bench-off_3
$\nu * |FT|^2$ of Cen X
$\nu * |FT|^2$ of Cen Y
frequency ν
0
1000
2000
3000
4000
10^{-2}
10^{-1}
10^{0}
10^{1}

Challenges for ongoing and forthcoming surveys

- **Detectors effects**
  - Precise calibration
  - Impact on cosmological observables
- **Systematics**
  - Blending
  - Intrinsic alignment
- **Modeling of the observables**
  - Evolution of the universe on small scales (in different models)
  - Speed and accuracy of numerical computations
- **Cosmological analysis**
  - cosmological parameter estimation
  - tension metrics
  - blinding

Take away: weak lensing to probe cosmic acceleration

<u>Towards high precision measurements</u>

- Weak lensing to constrain modified gravity:
  - beware of intrinsic alignment;
  - promising constraints from future surveys.

- PPL to characterize detector effects

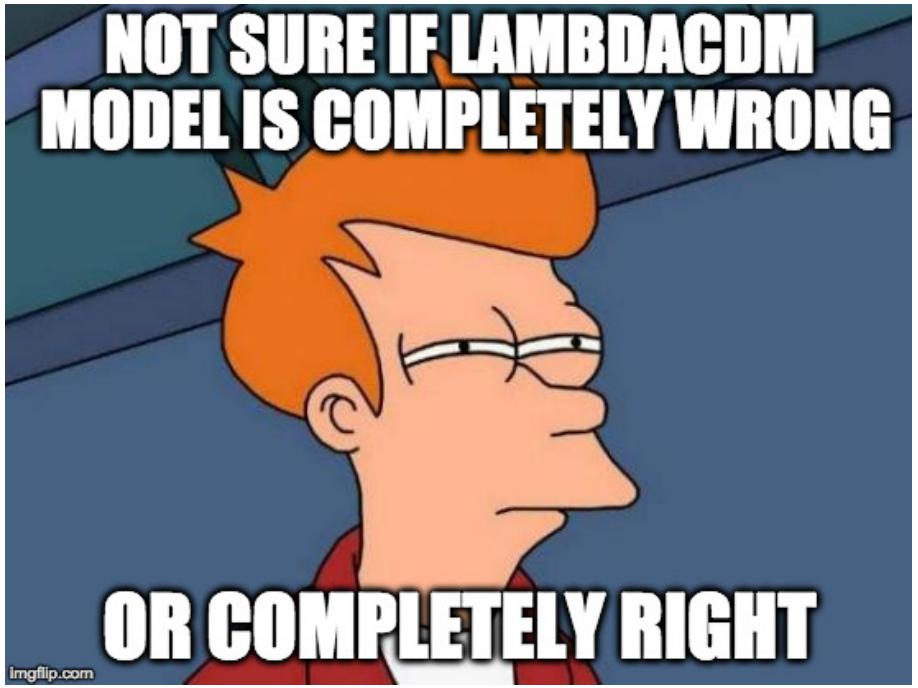
<u>Dark Energy Survey Year 1:</u>

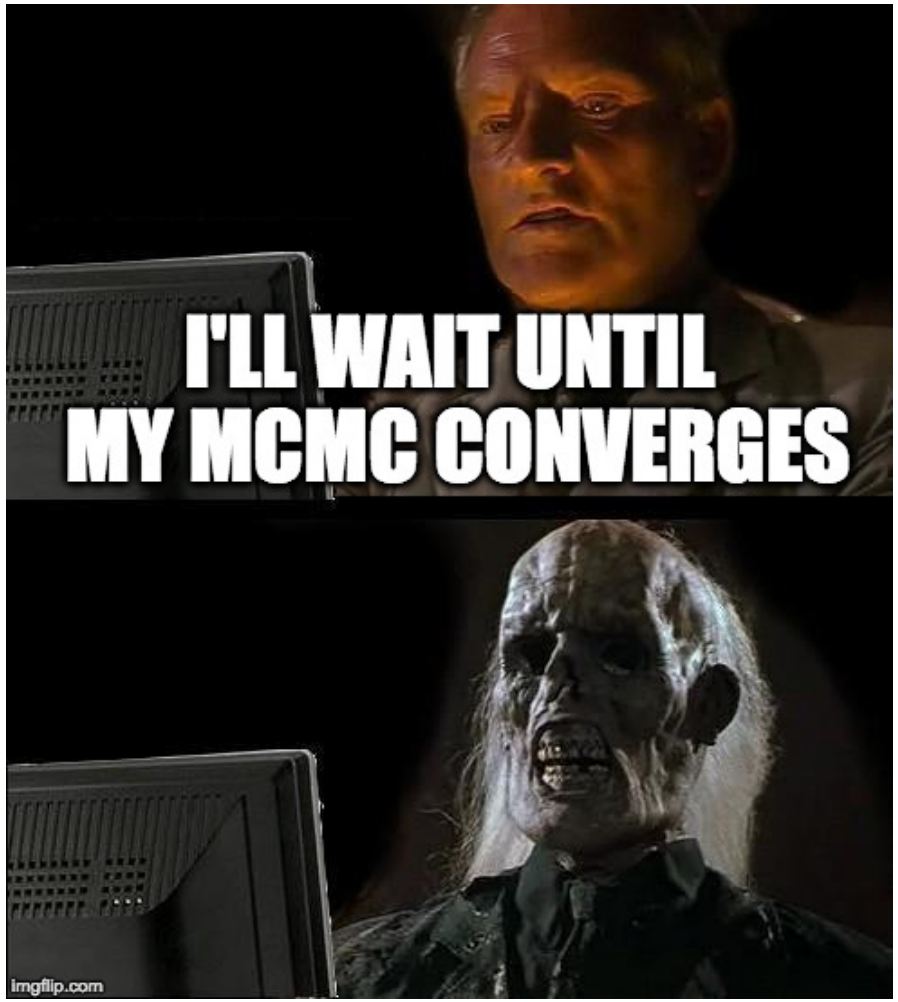
- Main constraining power on extensions to ΛCDM model: modified gravity.

- No evidence for deviations to ΛCDM but tensions to investigate.

- Preparing for DES Year 3: more data, more combination of observables, more models!

Some challenges for ongoing and forthcoming surveys in memes





Back up slides

	DES Y5	**LSST**
Sky coverage (deg^2)	5000	18000
Number redshift bins	5	10
n_{gal} ($/\mathrm{arcmin}^2$)	10	55
σ_ϵ per bin	0.25	0.2
$\sigma(z)$	$0.05(1+z)$	$0.02(1+z)$

TABLE II. Specifications for DES Y5 and for an LSST-like survey, used in our Fisher analysis.

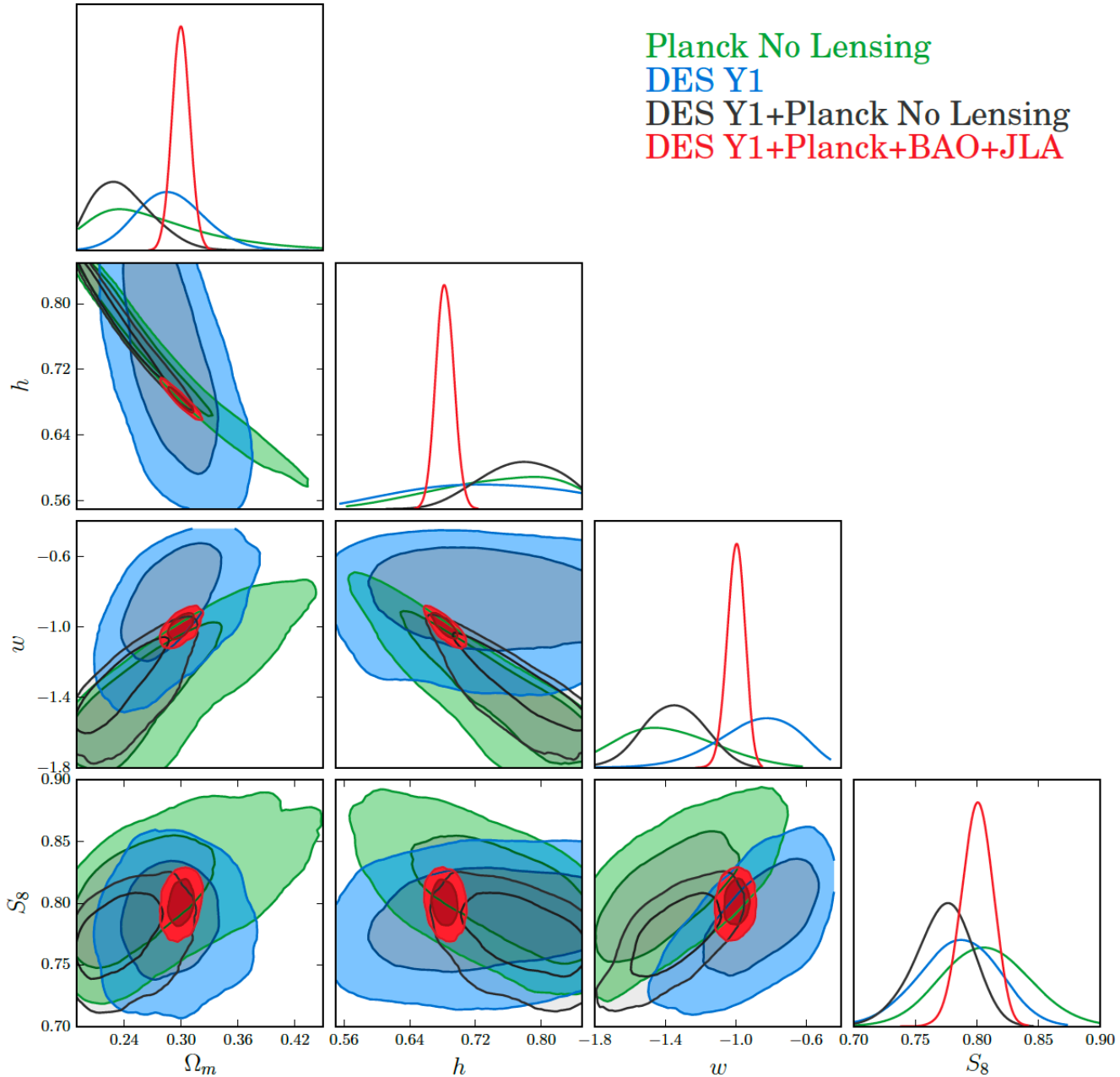
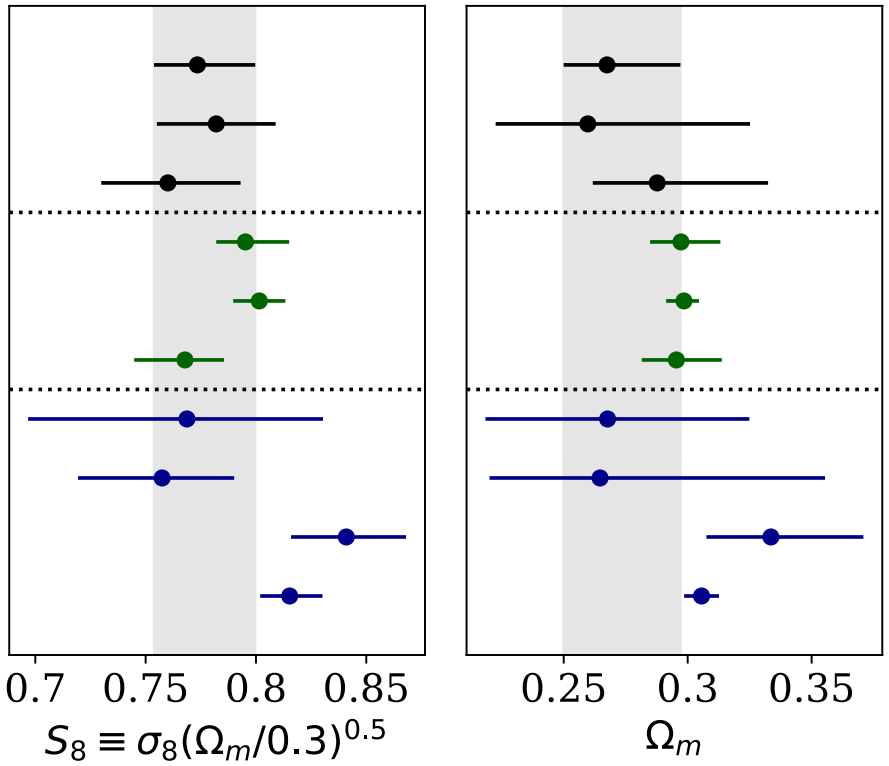
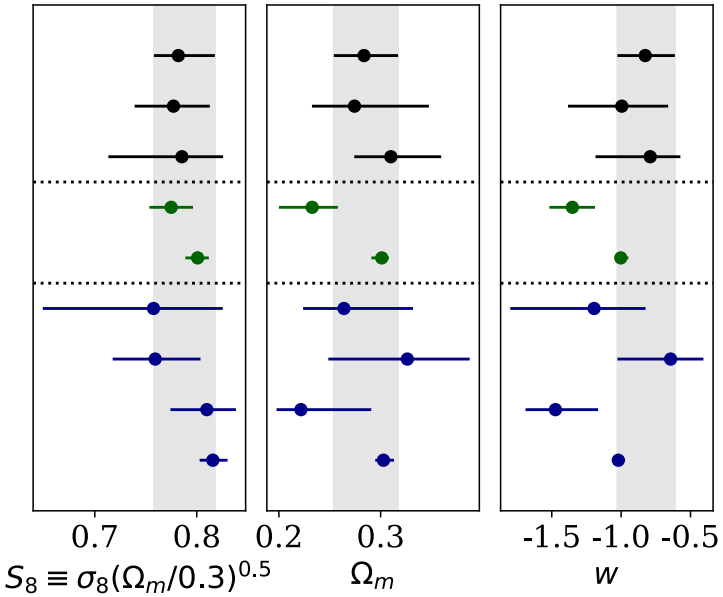


FIG. 14. wCDM constraints from the three combined probes in DES Y1 and Planck with no lensing in the Ω_m-w-S_8-h subspace. Note the strong degeneracy between h and w from Planck data.



DES Y1 All
DES Y1 Shear
DES Y1 $w + \gamma_t$
DES Y1 All + Planck (No Lensing)
DES Y1 All + Planck + BAO + JLA
DES Y1 All + BAO + JLA
DES SV
KiDS-450
Planck (No Lensing)
Planck + BAO + JLA



DES Y1 All
DES Y1 Shear
DES Y1 $w + \gamma_t$
DES Y1 All + Planck (No Lensing)
DES Y1 All + Planck + BAO + JLA
DES SV
KiDS-450
Planck (No Lensing)
Planck + BAO + JLA

Systematics modeled with nuisance parameters.

e.g. intrinsic alignment =

$$P_{IA}(k,z) \propto A_{IA} P(k,z)/D(z)$$